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Science and Technology in Composite Materials: Functionally Gradient Materials

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[FBIS Translated Excerpts] In this paper, the concept of functionally gradient material (FGM) will be explained; the steps and thought processes of designing a functional gradient, based on an example targeting thermal stress alleviation, will be introduced; various production methods for FGMs will be discussed; and finally, new development into functional fusion and high-degree functionalization through gradient formation will be discussed.

By the formation of an FGM, a spatially or temporally non-uniform and non-equilibrium state is created within a material with the aid of the concept on functional elements. In this sense, it is to be stressed that an FGM will have diverse and flexible functions, and actual examples of thermal stress alleviating heat-resistant materials, heat/electric energy conversion-capable materials, and symmetrical FGMs will be explained. This paper will show the readers that the concept of gradient formation will create new applications for material science and technology, and that these applications are expected to have many flexible possibilities.

1. Introduction

Roughly eight years have passed since the term "functionally gradient materials" was first heard. Around 1985, a group of researchers in Sendai proposed the new material concept called functional gradient. Since then, R&D activities have flourished in an effort to design, produce and evaluate heat-resistant materials with a functionally gradient structure in order to be able to alleviate thermal stress.

The idea of functional gradient was incorporated into not only ceramic/metal-based heat-resistant materials, but also many other materials, including inorganic, metallic, polymeric, organic and biological materials. Some of the already implemented cases have already been described in the special edition of this journal under the title of "Functional Gradient Materials."

Recently, as will be discussed later in this article, the concept of gradient formation has been used for fusing a functional material with a structural material in trying to develop a composite energy conversion system by combining thermal power and thermoelectric power generation.

Today, FGM research is carried out all over the world, as shown by the 150 papers scheduled to be presented at the third FGM international conference in Lausanne, Switzerland, in October 1994.

Nevertheless, in order to be able to predict how significant gradient formation will be for future material development, one needs to examine what gradient formation means, develop a strategy for theoretical systematization for structural and functional design in addition to evaluation, and examine the possibility of developing an economical process. Presented in this paper is an attempt to describe the potentials of functional materials, based on the above examination.

2. Concept of Gradient Formation

Based on a heat-resistant material for thermal stress alleviation, a conceptual image of an FGM is depicted in Figure 1. According to the diagram, this FGM is "a material consisting of an excellent heat-resistant and heat-insulating ceramic material on one side, and a tough and thermally conductive metallic material on the other, with gradually changing compositions in between, thus, capable of manifesting functions of the two materials and alleviating thermal stress caused by the difference in the thermal expansion coefficients of the two materials." There are people who say that the bonding or coating of ceramics has been done for a long time to create similar materials, and there are those who believe that FGMs are only another type of structural material that combines different materials. Both criticisms are valid in that attempts have been made in the past to create various intermediate layers in a material for alleviating thermal stress. Going back in history, we find that Japanese samurai swords, made to be tougher than any other material by having different carbon contents of iron between its surface and inner part, were good examples of FGMs.[1]

However, the structure of these swords and perhaps other similar materials was a solution to a specific technical problem, and was not recognized as based on a concept common to all materials.

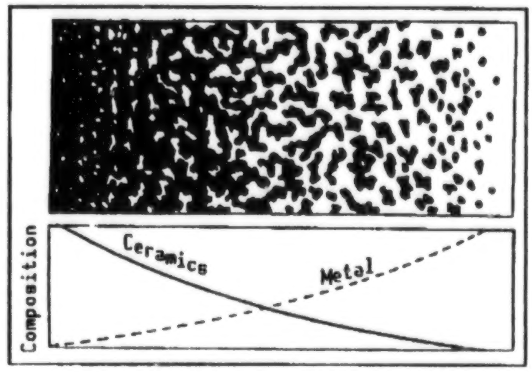

Figure 1. Conceptual Diagram of Functionally Gradient Material

Several years ago many researchers joined forces to conduct a survey concerning applications of FGMs. The group realized that it was necessary to have the common understanding of FGMs within itself. After discussions, FGMs were defined as "unitized materials that have continually changing functions spatially or temporally." "The change of functions with time" was specially added because FGMs were to include controlled drug-releasing materials and biological materials that would change their functions, such as drug administration, with time and environmental

change. As will be explained later, this concept of time-dependent gradient will have a more important meaning than what was just mentioned.

In trying to form a functional gradient, one needs to re-define "function." According to the Kojien dictionary, a function is defined as "an action that is a unique role to be played by each factor of an object whereby the factors are related to each other, or an action by an object." Although material function is usually considered to denote work or action by a material, it is necessary to think of forming a gradient of composition by factors in order to create a functional gradient. If one considers such factors that are the units for manifesting function to be functional elements,[2] there can be many functional elements, such as pores and particle shapes, in addition to chemical compositions. These items that can be functional elements for a material are listed in Table 1. A unitized material can be made to be equipped with diverse functions by consistently organizing these functional elements, with their mutual relationships taken into consideration. One of the ways to realize such a material can be to create an FGM.

Previously, uniformity was so emphasized in material development that fantastic success was achieved by creating highly pure, flaw-free, uniform materials as a whole, regardless of whether the materials were simple or composite ones. On the other hand, non-uniformity in materials was avoided at all cost because it was considered to cause weakened function manifestation or material deterioration. In contrast, FGMs can be said to be non-uniform materials within which non-uniformity has been intentionally designed. Shown in Table 2 is the comparison of different technologies for creating composite materials.

Table 1. Examples of Functional Elements

Composition	Ceramics, metals, polymers and organic matter
Structure	Single crystalline, polycrystalline, glass, amorphous, interstitial, porous
Shape & size	Particle, pillar, plate, fiber, large, small, long, and short
State	Solid, liquid, gas, and fluid
Quantized material	Electron, positive hole, ion, dipolar moment, and magnetic moment
Biological material	Amino acids, proteins, cells, and organs

		Hybrid material technology	Gradient formation technology	Composite formation technology
Design idea		Composite formation at molecular/atomic level	Compound assistance or application for adapting to use environment or function	Synergization of strengths of component materials
Structural control region		01. nm~0.1 μm	10 nm ~ 10 mm	0.1 μm ~ 1 m
Bonding mode		Intermolecular	Intermolecular/chemical bonding/physical bonding	Chemical bonding/ physical bonding
Structural consistency	Micro-scale	Uniform/nonuniform	Uniform/nonuniform	Nonuniform
	Macro-scale	Uniform	Nonuniform (continuous structural distribution)	Uniform
Functional consistency		Consistent	Gradient	Consistent

Table 2. Comparison of Technologies for Creating Composite Materials[2]

The author's group has already gotten so used to the concept of uniformity that it has become well aware of the fact that natural objects, i.e., animals and plants, and other materials around us are not usually uniform. The earth itself can be regarded as a structural body with a compositional gradient formed by differential densities. Previously, various functions could be improved to their maximum limits by pursuing material uniformity, whereas the concept of non-uniformity will add diversity and flexibility to functions because of the following reason. Non-uniformity is a non-equilibrium state that can tolerate dissimilarity and holds latent force or energy based on the shift from an equilibrium state in lacking spatial and temporal balances. Thus, it is clear that gradient formation is closely related to the concept of these non-uniformities.

3. FGM Design

To create an FGM, one has to wisely select its functional elements and design the optimal gradient structures for the elements. Different functional elements are mutually connected with each other in a complicated manner through a structure, i.e., composition and organization. Therefore, it is necessary to obtain computer support for numerical analyses and simulations to be able to predict and diagnose the FGM's micro- and macro-scale properties and its responses to use-environments.

As a simple example of compositional gradient design for the purpose of alleviating thermal stress, the study by Watanabe's group will be discussed.[3] The group chose particles of both partially stabilized zirconia and stainless steel as the functional elements and designed an optimal gradient structure that was to be formed by sintering and was considered to be most suitable for thermal stress alleviation. Zirconia, with a high melting point of 2,850°C and a low thermal conductivity of 3 W/m/K, is suitable for heat insulation, although not as satisfactory for oxygen ion conductance at a high temperature. Zirconia neither reacts with stainless steel nor presents any problem from the standpoint of cost.

Thermal stress is generated when thermal strain, caused by a spatial or temporal temperature change, is restrained. Problematical thermal stress can be caused by the difference in thermal expansions of the elements of a material in the cooling process of its production, or it can be generated by a temperature gap during the usage of a material. As an example of thermal stress created during production process, it was calculated that when cylindrical zirconia and stainless steel were directly bonded, a maximum axial-direction tensile stress greater than 1,000 MPa was generated in the ceramic-side peripheral surface in the vicinity of the bonded plane. Such a tensile stress can be reduced by 50 percent by the formation of compositional gradient, with the actual magnitude of reduction depending on the manner in which the gradient is formed.

Shown in Figure 2 is the relationship between the maximum specific stress (stress/material strength) and the compositional profile for a thermoelastic model as analyzed by the finite element method. The compositional profile is given by $C = (x/d)^P$, with d being the gradient's width. The diagram clearly indicates that the thicker the gradient layer, the lower the maximum stress and the more alleviated the thermal stress. The diagram also shows that there exist optimal compositional profiles with their minimums occurring roughly at P = 0.7 and with d being kept constant.

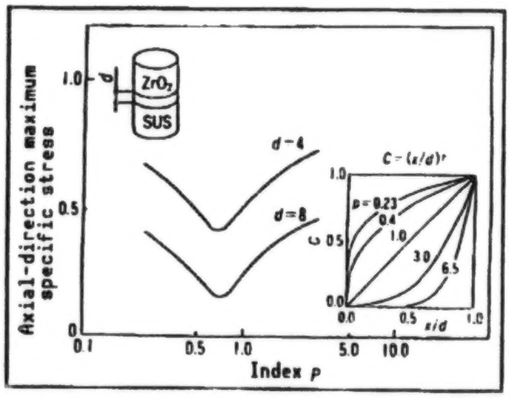

Figure 2. Relationship Between Compositional Profile and Axial-Direction Maximum Specific Stress for Cylindrical Zirconia/Stainless Steel FGM

Quite complicated but intriguing in designing a gradient structure is the relationship between micro-scale structure and macro-scale properties. As shown in Figure 1, moving from one side to the other of this ceramics/metal gradient structure, there is, first, a uniform ceramic section at the beginning; a dissimilar element begins to appear in the next section; and the concentration of the dissimilar element increases to create an intermediate state which belongs to neither ceramics nor metal. After the intermediate state, the concentration of a ceramic material begins to decrease; the matrix changes into metal; and finally, a uniform, metal composition section is reached at the other end. Throughout the complicated transition of structure, there are the shapes of functional elements like prism, plate or fiber, but are they dispersed, or clustered? In general, macro-scale properties of a material are influenced by its structure, and the state of a structure with a given composition is determined by the elements' shapes and the formation process conditions. In order to analyze the relationship between the structure and macro-scale properties and construct a model with estimated properties, it is helpful to use recently fashionable, new mathematical theories and ideas. These theories and ideas include topology, the technique for quantitatively analyzing the complex state of structure and its transition, i.e., the technology for dealing with the continuity in diagrams; "percolation" to deal with the relationships among elements; "fractal" to deal with intermediately ordered or random systems; "fuzzy" to deal with ambiguity; and "chaos" to deal with complexity and unpredictability.

Watanabe et al. obtained a fractal dimension for the stainless steel phase in a zirconia/stainless steel system.[4,5] Fractal denotes a system that shows a complex form of repeating and expanding series of simple patterns and that

is characterized by its self-similarity, in which a fine segment, when expanded, shows a pattern resembling the total segment.[6] A fractal dimension takes a non-integer value, e.g., a fractal dimension of 1.5 in the relationship in which an area is proportional to the power of 1.5 of a length. The dimension can be regarded as the index for expressing the complexity of a shape. In a two-dimensional space, a fractal dimension of 2 means a smooth shape.

A fractal dimension in a two-dimensional space is expressed by Equation (1) as the relationship between the area of the phase contained inside a circle placed on a diagram (the α phase in the Figure 3 diagram) and the radius of the circle.

$$M(r) = r^D \qquad (1)$$

where r is the radius of the circle; M(r) is the area of the phase contained within the circle with a radius r; and D is the fractal dimension.

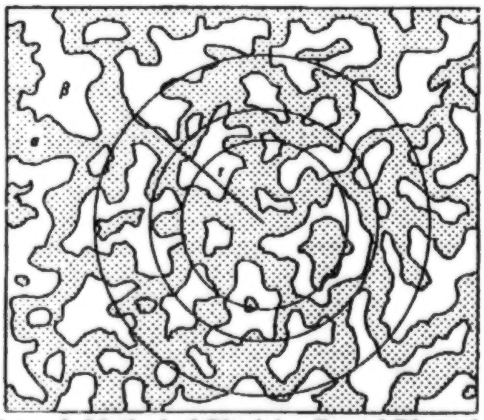

Figure 3. Method of Obtaining Fractal Dimension (for the α phase)[4]

The fractal dimensions obtained according to Equation (1) for the stainless steel phase in the zirconia/stainless steel FGM are shown in Figure 4 to be composition-dependent.

According to the percolation theory, a fractal dimension is 1.896 for the formation of infinitely continuous clusters, and the size of an isolated cluster rapidly decreases with a composition either larger or smaller than the critical composition.[7] Therefore, it is safe to assume that the stainless steel phase matrix is formed in the vicinity of zirconia's volume fraction of 0.25, corresponding to a fractal dimension of approximately 1.9. With zirconia's volume fraction at 0.2, the fractal dimension becomes 2, indicating that the stainless steel phase is completely aggregated, i.e., zirconia grains are uniformly dispersed in the stainless steel matrix. Also, when zirconia's volume fraction is in a range between 0.4 and 0.5, the fractal dimension is approximately 1.7. With this fractal dimension, clusters of both stainless steel and zirconia phases are assumed to form a non-continuous, conjugate network structure. Clusters at a composition of 0.5 have been

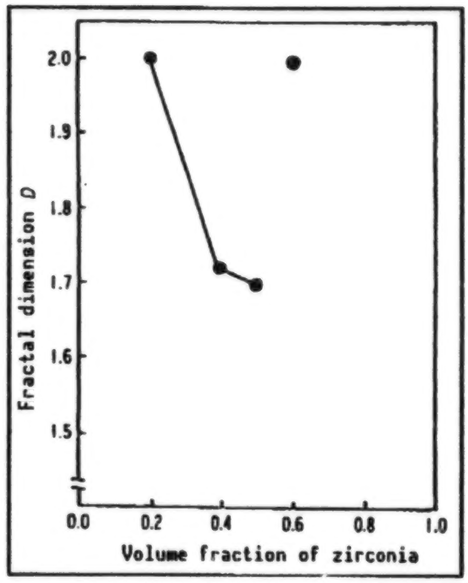

Figure 4. Composition Dependency of Fractal Dimensions for Stainless Steel Phase in Zirconia/Stainless Steel FGM[4]

analyzed to have an average size of 10 μm. With a composition of 0.6 for zirconia, the fractal dimension becomes 2 again, and it is safe to assume that the stainless steel phase now becomes the dispersed phase.

How do macro-scale properties of a material vary with the transition of structure consisting of functional elements? Shown in Figure 5 are the qualitative relationships of properties such as thermal conductivity, electric conductivity, toughness, Young's modulus, and bending strength to the composition. These properties, with the exception of Young's modulus and strengths, have a trend of following the curve (a) of the diagram. Thus, these properties show a drastic change when zirconia's volume fraction exceeds 0.25, or when the stainless steel phase begins to lose its matrix characteristics, and the properties become basically that of zirconia when its volume fraction surpasses 0.8. On the other hand, Young's modulus and strengths often display the tendency of the curve (b), with a noticeable dip in the vicinity of a zirconia's volume fraction of 0.4 to 0.6. These mechanical properties, which are affected by the presence of pores and flaws in a material, do not necessarily show the tendency of the (b) curve, although it has been analyzed that the probability for the detachment at grain surfaces to occur becomes greater in a region where large, dissimilar clusters are present. Incidentally, these analyses were carried out in three dimensions, although there appeared to be no significant difference between the results of these analyses and those of two-dimensional analyses.[8]

Also significantly affecting macro-scale properties are the shape and orientation of functional elements, including pores. Researcher Wakashima has been studying the composite rules between micro-scale structure and such properties as elastic modulus, thermal expansion coefficient,

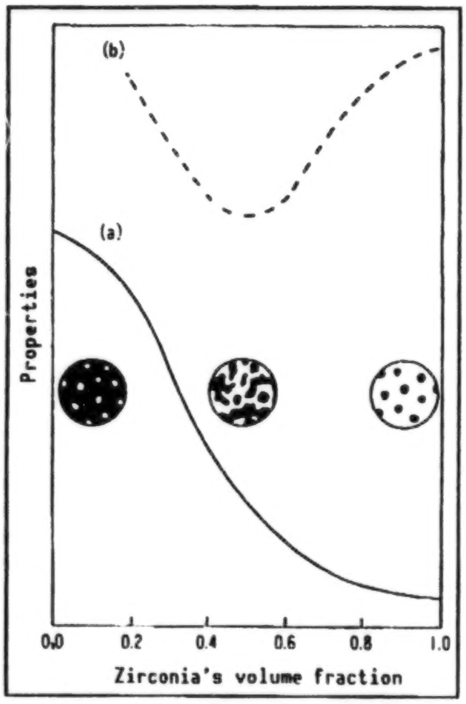

Figure 5. Composition Dependence Tendencies for Properties of Zirconia/Stainless Steel FGM

specific heat and thermal conductivity for mixed systems.[9] For FGM design, it is important to systematically understand both theoretical and experimental relationships between these structure/composition and macro-scale properties and store them in a database for easy access later.

The next step in FGM design is to select functional elements and determine the process with which a gradient structure is to be formed with the elements, so that the resulting FGM will have functions appropriate for use conditions. In other words, the design sequence becomes the reverse of the normal design sequence in which an optimal gradient structure is sought to fit a combination of required functions.

The reverse design sequence used for designing a thermal stress-alleviating, heat-resistant material is shown in Figure 6. Information necessary for design includes basic information concerning functional elements and production methods stored in a knowledge base; composition distribution functions; a micro-scale structure model and a characteristic-estimated model based on the micro-scale structure model; and various properties of functional elements and non-gradient materials (uniform-composition composite materials) which are stored in a material property database. Such an FGM design support expert system has been developed by Hirano *et al.* According to the system, after determining the property values at an arbitrary composition, one is supposed to hypothesize a gradient composition distribution; apply, if necessary, a fuzzy membership function to any ambiguity in the structure; and seek, through repetitive analyses of temperature distribution and thermal stress, the combination of composition-distribution profile and elements that will minimize specific stress.[10]

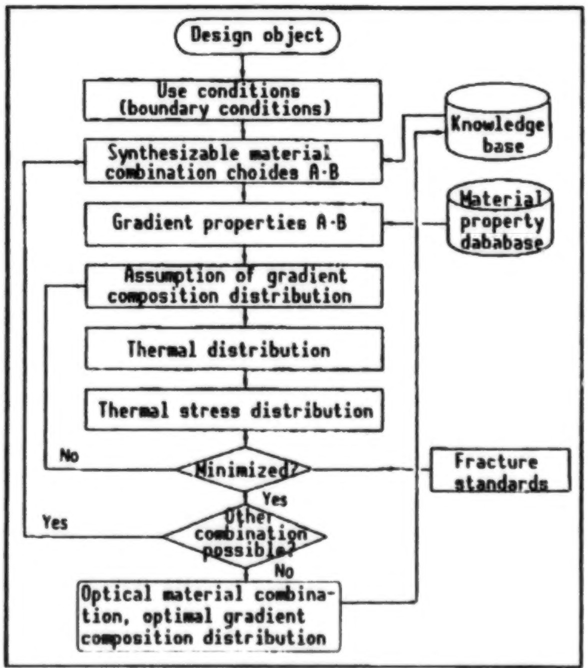

Figure 6. Reverse Design Sequence for FGM[10]

Today, an increasing number of analyses, not limited to thermal stress analyses, and data necessary for gradient formation are being accumulated. Also, more model theories are being developed, and computer technology is showing rapid progress. Under these circumstances, it is safe to assume that someday in the near future, an expert system will be able to instantly give several choices of answers, without property measurements for materials of various compositions, to questions like how to combine required functions, and what kinds of function will be manifested when two or more functional elements are incorporated in gradient formation.

4. Control Processes for Gradient Structure

In the above discussions, examples of thermal stress-alleviating material were cited, for which FGM design research showed significant progress. How can these materials be constructed? Unlike the production of uniform;

materials, it is difficult, from the standpoint of technology and cost to produce non-uniform materials under the same temporal and spatial conditions. Major processes that have been developed to challenge the above difficulty include the gas-phase control methods by CVD, CVI and PVD; the solid-phase control methods by sintering and SHS method; and the liquid-phase control methods by plasma melt-injection, infiltration and plating. Each of these methods was the modified version of an existing process to be able to control the formation of a gradient structure.

(a) Gas-Phase Control Methods

The gas-phase control method is a technique for producing a gradient by synthesizing functional elements through precipitation from the gas phase. This method is advantageous in its flexibility of being able to be applied to the production of small and simple to large and complex objects, and in being reasonable, cost-wise, because of its capability of controlling gradient compositions. A 30-cm cubic gradient material based on SiC/TiC/SiC woven fibers has already been produced by a CVD-based gas-phase control method.[11] In this process, it is critical that both reactions of a plural number of raw material gases and shape/structure of pores and precipitated grains be controlled and that cracks and delaminations due to thermal stress be prevented.[12] Also, CVI was found to be an effective means for gas-phase control, as shown by the following example. In this example, a nose cone-shaped SiC/CC gradient composite was produced by a CVD/DVI-combined gradient composite formation process, i.e., by the combination of the impregnation of a piece of carbon fiber fabric with C and SiC vapor to form a gradient composition, and the CVD formation of a SiC layer on the surface. This composite was tested to be able to withstand exposure to 2,000K combustion gas from a rocket engine at Mach 3.[13]

(b) Solid-Phase Control Methods

The solid-phase control method involves molding a material by laminating raw material powders to form gradient compositions and hardening the material by sintering or reaction-sintering. This method is suitable for producing bulk materials. In order to produce thoroughly dense materials, it is effective to use pressure-sintering with a hot press or HIP, or to carry out post-HIP treatment. There are several methods for laminating raw material powders: e.g., the computer-controlled, continuous, automatic laminating method,[14] the doctor blade method,[15] the centrifugal laminating method,[16] and the step-wise composition lamination method. In many cases, it is sufficiently effective to use the step-wise composition lamination method involving only three to five steps.

In the sintering process, it is critical to appropriately adjust the temperature and shrinkage rate according to compositions.[3] In the SHS method, a material is made semi-melted by the sudden release of reaction heat and is solidified instantaneously. Thus, although one need not be concerned with differences in sintering temperatures if thermal stress alleviation has been taken care of by gradient design, one needs to control micro-fine structures to assure full manifestation of functions. The sintering method has already been applied to the development of the above-mentioned examples of zirconia/stainless steel-based, SiC-AlN/Mo-based[17] and W/Cu-based[18] FGMs. TiC/Ni-based[19] and TiB_2/Cu-based[20] FGMs have been developed by the SHS method. Elsewhere, the laser sintering method[21] and the discharge sintering method[22] also appear to be promising.

(c) Liquid-Phase Control Methods

In the liquid-phase control method, functional elements are either precipitated or solidified from the liquid phase and deposited on a substrate in a gradient fashion. One of the liquid-phase control methods is the plasma melt-injection method, which has been developed in two different ways: one using one plasma torch that melt-injects raw material powders which are metered to the torch in an automatically changing composition[23]; and the other using two or more torches each of which is independently controlled for melt-injection.[24] Both these plasma melt-injection methods are carried out under reduced pressure in order to prevent the oxidation of metallic elements, minimize the creation of pores in coating films, and maximize the film's adhesion strength. The melt-injection method is a practical process that permits thick-gauge gradient layers to be formed in a comparatively short time on a substrate object which can be large and complex. Technically speaking, this method requires good control over any different melt-injection conditions for different powders, and improvement in porosity and adhesion, which are the two inherent problems of the method. Using the plasma melt-injection method, gradient films of zirconia/NiCr[23] and zirconia/NiCrAlY[25] were produced.

In the electrolytic precipitation method, a substrate electrode is immersed in a plating solution containing metal ions, and the ions are electrolytically deposited on the cathode by reduction. In this process, when micro-particles of ceramics or resin are dispersed in the plating solution with agitation, these particles will be deposited with metal ions. Therefore, a gradient plating layer can be deposited by changing the concentration of the dispersed phase. A dense, pore-less ZrO_2/Ni plating film was made by this method.[26]

(d) Composite Control Methods

Composite control methods—in which either the gas- and liquid-phase methods or the solid- and liquid-phase methods are combined to use the advantages of both methods and compensate for each other's disadvantages—have also been developed. For example, in the production of a diamond/WC FGM, potentially applicable for a heat sink, made by the CVD/plasma melt-injection method, the diamond film was formed by the simultaneous actions of coating WC particles with plasma flame and decomposing methane gas in the same flow as the particles.[27] The previously mentioned W/Cu FGM was produced by the combination of sintering and infiltration. A combined electrolytic precipitation/sintering method was used to produce a perfect ZrO_2/Ni FGM by producing, first, an FGM containing a metallic phase of approximately 60 volume-percent by the sintering method, followed by electrolytic precipitation to add up to 100 volume-percent metallic phase. This method is an excellent example of the composite method, because it is difficult to create an FGM

containing a 100-percent metal section by sintering, whereas it is difficult to carry out a plating process with the electrolytic precipitation method when the ceramic phase becomes the majority.[15] Other possible combinations of processes include CVD/sintering, melt-injection/sintering, and CVI/melt-injection, in addition to the already discussed CVD/CVI.

In addition, there are such processes as sol-gel, hydrolysis, and co-polymerization. Nevertheless, various processes that are simple and convenient and will permit spatial and temporal control of the structure need to be developed.

5. Functional Fusion by Gradient Formation

A gradient structure is not limited to the domain of structural materials; it has also been seen in functional materials, and its diverse applications are anticipated in these materials. Optical fibers have a gradient refractive index in the radial direction in order to cause total reflection of light in them. For a long time, research has been conducted to utilize the inner field effect of a semiconductor with a gradient of band gap.[28] These compositional gradients, including those in structural materials, were created in order to disperse strain energy and prevent it from concentrating locally in thermal stress-alleviating materials, to displace potential energy of electron polarization in optical fibers, and to change position energy of conducting electrons or positive holes gradually or locally. It is clear that these functions are generated by the use of a shift from an equilibrium state. If any energy state is off, the equilibrium state is called "gradient potential," and it will be possible to use the concept of gradient potential design to design functions that will exceed the frames of structural and functional materials. Although a temperature gap causes a non-equilibrium heat flux and thermal stress problems within a material, the gap can be utilized for thermoelectronic and thermoelectric power generation. An attempt is being made to apply the concept of gradient formation to the development of energy both on the ground and in space to meet the increasing demand. In 1993, the Science and Technology Agency-supported R&D project concerning super-high-efficiency energy composite conversion systems was initiated in an attempt to combine the thermoelectronic and thermoelectric methods of power generation. The idea is to harness either solar energy or the decay heat of a radioisotope as the thermal energy source, separately generate vacuum-radiated thermoelectrons at a high-temperature side of 2,000K and inside-solid majority carriers with semiconductor's pn junction at a temperature below 1,100K, and directly convert them into electric energy. A conceptual diagram for the heat/electric energy composite conversion system is presented in Figure 7.[29]

The system basically consists of a heat collector, a thermoelectronic conversion device, a thermoelectric conversion device, and a heat radiator. There are areas of further development for the system; they include the storage of heat, from collected solar energy, and the transport of heat using heat pipes between the thermoelectronic and thermoelectric conversion devices. For the heat collector, a TiC, Ni and W-based compositional gradient structure, made by plasma melt-injection, is being examined to cope with the requirements for heat resistance, high radiation efficiency, and high thermal conductivity.

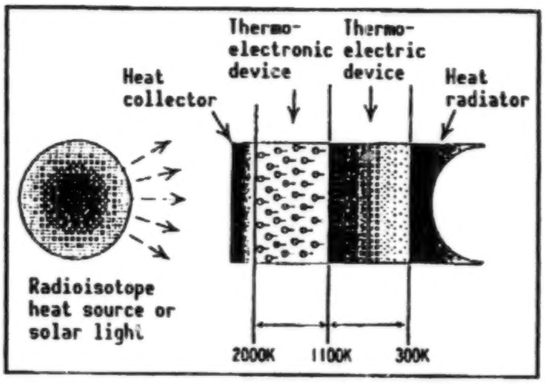

Figure 7. Conceptual Diagram for Heat/Electricity Composite Energy Conversion System

Shown in Figure 8 is the diagram of principles involved in the thermoelectronic conversion device. Thermoelectrons emitted by the emitter electrode at the high-temperature side are captured by the collector electrode at the low-temperature side, and they are converted into currents. The process is exactly analogous to that for thermal energy being converted into electrons' potential energy, and the difference in the potentials between the times of emission and capture will be taken out as electric power. Therefore, in order to increase the conversion efficiency, it is mandatory to (1) lower the work function of the emitter to make it easier for electrons to be released; (2) effectively neutralize electric charge in the space with a small amount of sealed-in cesium ions to reduce the internal loss; and (3) lower the work function of the collector electrode to reduce the collector loss. Members involved in the above-mentioned project are expecting to achieve a high conversion efficiency of 20 to 35 percent by using an emitter with the below-described structure, a WO_3/W-based gradient collector electrode with a low work function, and an inter-electrode distance of less than several tens of μm. The emitter is constructed with a compositional gradient, which is made by embedding Nb-Ta islets with a high work function (φE ion) for efficiently ionizing cesium gas, on the surface of the W-Mo electrode with a low work function (φE electron) with an intermediate layer of Al_2O_3 for diffusion prevention.

Incidentally, a conversion efficiency of 15 percent has been achieved with previous attempts of thermoelectronic power generation. In this field, Russia is the R&D leader of the world. Several times since 1980, the 1-ton Topaz thermoelectronic generator that uses a compact nuclear reactor as the heat source to generate an output of 6 kW at an efficiency of 7 percent, has been carried by a spacecraft.

The performance index, Z, for a thermoelectric conversion material, which is expressed by the following equation, generally peaks to a maximum at a specific temperature and decreases sharply at other temperatures.

$$Z = \alpha/\rho \times \kappa \qquad (2)$$

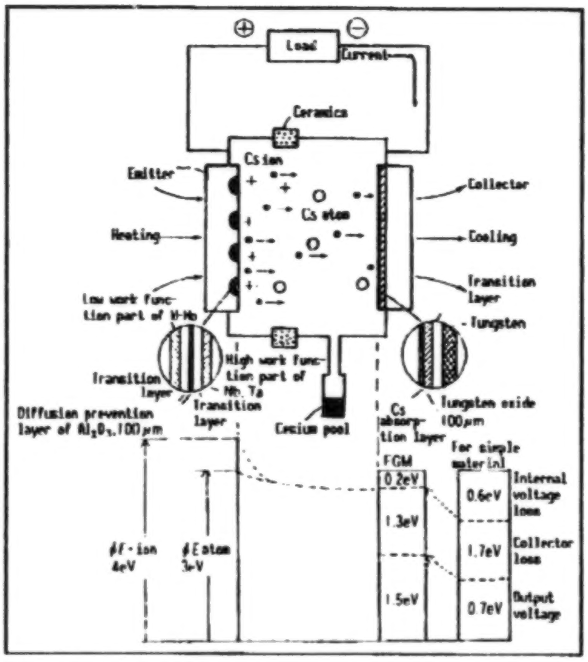

Figure 8. Model Diagram for Thermoelectronic Generator With Gradient Structure

where α is thermoelectric power, ρ is specific resistance, and κ is thermoconductivity.

The project in question is aiming at achieving a high conversion efficiency of more than 20 percent by preventing the performance index from decreasing in a wide temperature region through the formation of compositional gradients with respect to the carrier concentration and among dissimilar materials, as shown in Figure 9, based on the optimal gradient potential design theory.[31] Examination is under way concerning the formation of compositional gradients with respect to the impurity concentration and among the functional elements in each of the three temperature regions, i.e., the Bi_2Te_3-based low-temperature region (to 350K), the PbTe-based medium-temperature region (to 800K), and the SiGe-based high-temperature region. Incidentally, the United States is the world's leader in thermoelectric generation development. Its thermoelectric generator, which uses ^{238}Pu as the heat source and generates an efficiency of approximately 6 percent, was carried by the Voyager planetary surveyor (with an output of 150 W per unit) and the Galileo Jupiter surveyor (with an output of 300 W). This generator has also been used as a power source in remote areas.

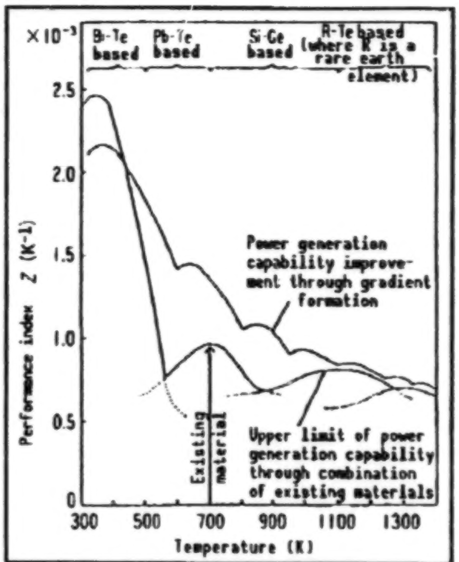

Figure 9. Expected Improvement of Performance Index for Thermoelectric FGM[31]

Also, in the project, studies are being carried out concerning the construction of electrodes in a high-temperature region, junctions between devices, thermal stress alleviation, diffusion prevention layer required for the compositional gradient segment, interfacial reaction control, thermal stability, and heat radiation. Thus, the concept of gradient potential design is being applied in many R&D areas.

An entire composite power generation system proposed for the project is designed to consist of two stacked units, one on top of the other, each of which has the heat source surrounded by six composite modules made of one thermoelectronic device connected to a number of thermoelectric devices. The initial targets for the system include an overall efficiency of 40 percent and an output of 300 W. The mission of this R&D project is to fuse a functional material with a structural material to develop a new field of directly and efficiently converting thermal functions into electric ones. R&D achievements in this project are expected to cause significantly propagative effects because the idea of gradient formation is being tested in many areas. Thus, there are many potential applications of the idea, including solar light power generation, nuclear power generation, waste heat-utilizing power generation, space and marine development, and uses in consumer devices.

6. Development of High-Order Functions Through Gradient Formation

Needless to say, the gradient potential design method using components called functional elements is expected to be able to combine two or more functions in one material, or to produce a material, the magnitude of whose functions can be doubled if its size is doubled. In addition to these primary capabilities, one can also expect the method to produce materials with non-linear, high-order functions, i.e., to manifest the synergistic effect of further amplifying functions of the elements or creating new functions that do not belong to any elements, in a material. For example, when a compositional gradient of ceramics/metal is expanded to a symmetrical compositional gradient of ceramic/metal/ceramic, the surface ceramic layers will be strengthened because strong compression stress is generated in the ceramic layers by the induced symmetry of strain gradient potential.

In other words, the ceramics are made stronger because the unitized material tends to self-restrain its bending moment, and the shift from equilibrium is forced into in-plane distortion when two functional elements with different thermal expansion coefficients are unitized in a symmetric fashion. Thus, the symmetric gradient potential of strain, without necessarily forming a compositional gradient, is indispensable for avoiding stress concentration at interfaces and producing a strong self-restrained state without peeling or cracking.

The author's group is trying to produce such symmetric FGMs by the SHS/HIP method. A molded material consisting of powders arranged to form a compositional gradient is self-sealed in a Pyrex glass container with the aid of BN powder, and the container is placed in a HIP device. The mold in the glass container is instantaneously sintered under high nitrogen gas pressure with the heat of nitration-combustion as high as 2,500°C of Si powder that surrounds the glass container. Using this method, it is possible to form a material with a dense structure in one step, despite the fact that its raw material powders have different sintering temperatures.[32]

Shown in Figure 10 is the compositional distribution of an $Al_2O_3/Cr_3C_2/Ni/Cr_3C_2/Al_2O_3$-based ceramic material made by the above-described method.[33] The size of this material is approximately φ30mm x 6mm. Its 1mm-deep top and bottom surfaces consist entirely of Al_2O_3, its inner part contains inwardly increasing amounts of Cr_3C_2 and Ni, and its center part shows a Ni content of 22 percent. It was revealed by X-ray stress measurements that an extremely high compression stress of 850 MPa in the radial direction remained on the Al_2O_3 surfaces without a significant decrease from center to periphery. The toughness value for the surface Al_2O_3, as determined by the IF method (with a load of 20 kg), was 11 MPa-m⁺, which was a fantastic improvement of 200 percent over that for an ordinary alumina ceramic material.

Furthermore, the toughness was even higher in the material's interior, with the center showing a toughness value of 15 MPa-m⁺. The FGM also showed high hardness of 22 GPa and a three-point bending strength of 850 MPa.

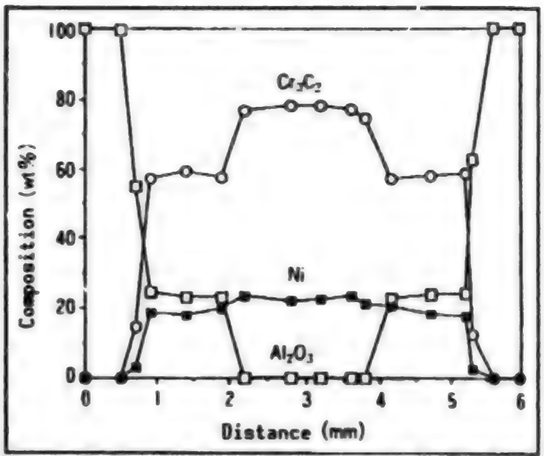

Figure 10. Compositional Profile of $Al_2O_3/Cr_3C_2/Ni/Cr_3C_2/Al_2O_3$-Based Symmetric FGM

In general, the toughness value, K_C, in the presence of the residual stress, σ_R, can be expressed by the following equation[34]:

$$K_C = K_C^0 \text{-(2/sq rt of } \pi)\sigma_R \text{sq rt of c} \qquad (3)$$

where K_C^0 is the fracture toughness value of the material free from stress, and c is the crack length.

The value of K_C was calculated according to Equation (3) with the following substitutions. A fracture toughness value of 4 MPa-m⁺ for the surface alumina in the absence of residual stress was substituted for K_C^0; a crack length caused by a large indenter load was substituted for c; and a residual stress value obtained from X-ray applied measurements was substituted for σ_R.

The result agreed well with experimental values obtained with various test specimens. Thus, it may be concluded that the residual stress had the effect of reinforcement. The author's group has appended the term "pre-stressed toughening" to such compression reinforcement, modeled after the expression "pre-stressed concrete."

It has also been understood by analysis that the residual stress due to compression is related not only to the difference in thermal expansion coefficients, but also to the micro-fine structure, as well as to the difference in contraction coefficients during the sintering process. It is conjectured that because Cr_3C_2 grains develop into an interwoven structure of prisms, the stress cannot easily be alleviated by plastic deformation, resulting in the significant residual stress. In the case of another FGM—$Al_2O_3/TiC/Ni/TiC/Al_2O_3$—the surface residual stress was approximately 200 MPa. It is speculated that the difference between this value and the value obtained for the previous material is attributed to the fact that TiC grains are isotropic in addition to the thermal expansion factor. Incidentally, the surface Al_2O_3 of this particular sample was found to show a fracture toughness value of 6.5 MPa-m⁺ and a strength of 1,200 MPa.[35]

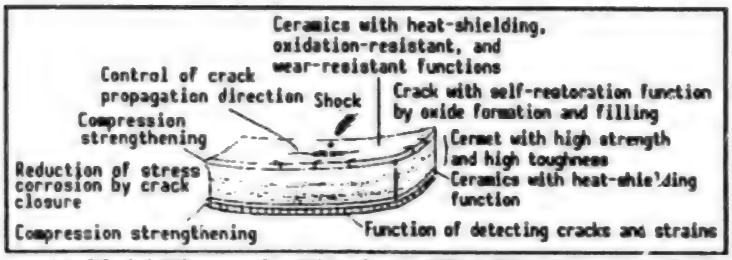

Figure 11. Model Diagram for High-Order FGM With Symmetric Gradient

Interesting phenomena associated with residual stress were observed. It was impossible to generate a crack unless an unusually large indenter load were applied. Residual stress in a test specimen that had been cut in a long, narrow piece became anisotropic, so that when a crack is initiated on the Al_2O_3 surface, the crack was observed to propagate in the longitudinal direction, but showed little or no propagation in the transverse direction of the test specimen. By taking advantage of this phenomenon, it may be possible to design a material shape that will guide cracks in the safer longitudinal direction.

Also, in this case, there is an interesting shift from the symmetric equilibrium of compression/tension/compression, i.e., the balance of tension. It has been confirmed by three-dimensional stress analysis that, although minor superficial cracks can be immediately restored by compression stress, slightly deeper cracks break the localized balance of tension and result in changes of strain on the other surface.[36] Such changes should be detected by attaching to the other surface a strain sensor made of a piezo-ceramic or film material.

It has been confirmed that when the surface of the previously mentioned $Al_2O_3/TiC/Ni/TiC/Al_2O_3$ is cracked and heated to near 1,100°C, oxides of Ti and Ni are formed in the crack to fill it up. Although it is not yet clear whether the crack filling by the oxide growth will restore the crack in terms of strength, it is safe to expect that the oxide growth will control further progress of the crack and prevent further internal oxidation.

Previously, R&D efforts were concentrated on developing methods of absorbing the fracture energy of cracks that had been generated, in order to strengthen ceramic materials. The attempted methods included crack deflection by grain dispersion, induced transformation of stress, and the cross-linking effect or the pull-out effect by fibers. However, in the future it will rather be more important to take multifarious, flexible measures, including the control and detection of crack generation itself and of its propagation direction and self-restoration, as illustrated in Figure 11.

As discussed, FGMs, made with a symmetric gradient between ceramics and high-strength cermet, have the potential of being applied to wide-ranging fields, including wear-resistant and corrosion-resistant impellers, tool materials, engine components, aerospace craft components, materials for nuclear and nuclear fusion reactors, high-temperature electrodes, and biological materials.

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AIST Develops Technology to Remove Toxic Substance From Ground Water

94FE0837A Tokyo NIKKEI SANGYO SHIMBUN in Japanese 26 Jun 94 p 2

[FBIS Translated Text] The Agency of Industrial Science and Technology's Government Industrial Research Institute, Hokkaido (GIRI, Hokkaido), has developed a technology that removes toxic substances from groundwater polluted by organic chlorine compounds, such as trichloroethylene used to clean plated and electronic parts. The polluted water passes through a treatment device that contains a metal reducing agent, which causes a chemical reaction that removes chlorine. The method is proven effective over longer periods than current treatment methods.

The newly developed cleaning method utilizes a metal reducing agent made of activated charcoal that has adsorbed iron grains. When organic chlorine compounds such as trichloroethylene passes through a reducing treatment device filled with the reducing agent, a chemical reaction occurs, and in approximately seven minutes the compound is reduced to chlorine ions and hydrocarbons such as ethylene, acetylene, and ethane; the chlorine can then be removed from the compound. It may be possible to reduce 200 micrograms (microgram = 1/1000 gram) of trichloroethylene per liter to 1 microgram per liter at temperatures of 10°C or less. In experiments, trichloroethylene concentrations have been kept below 2 micrograms per liter over a period of two months.

Chloroethylene Recycling Promotion Council To Reinforce Research in Dehydrochlorination

94FE0837B Tokyo KAGAKU KOGYO NIPPO in Japanese 20 Jun 94 p 3

[FBIS Translated Text] The Polyvinyl Chloride Recycling Promotion Council (Chairman Akio Sato, President of Mitsui Toatsu Chemicals, Inc.) recently determined this fiscal year's operation plan, which specifically calls for strengthening cooperative research on a method of dehydrochlorinating waste plastics containing polyvinyl chloride (PVC) prior to incineration and oil reclamation. This method has already been proven effective at the experimental level, but the Council wants to speed up the establishment of a full-scale system in cooperation with plant manufacturers.

In addition to work on PVC and albumen recycling, which are continuing projects, the Council's operation plan for this year covers a number of items on model recovery of PVC pipes and materials, including a survey on the actual conditions in the collection and recycling business and a study of the PVC Pipes and Joints Association's standards for recycled PVC.

Technological development on dehydrochlorination (increasing its scale) has once again been taken up by energy and resource recovery interests. Because of reports on an effective method for recovering hydrochlorides from waste plastics containing PVC before incineration or oil reclamation, the Council will first focus on the dehydrochlorination process, and then proceed with cooperative research with plant manufacturers to obtain concrete information, assuming full-scale dehydrochlorination. The Council also plans to conduct technical study and development of effective utilization of hydrochloric acid from recovered hydrogen chloride. The plant manufacturers that will engage in joint research have not been announced, but negotiations are in the final stages.

Other projects are continuing, such as testing of a small non-polluting incineration system and research on developing oil reclamation technology.

Nippon Sanso Develops Technology To Remove Dissolved Oxygen Up to 0.2 ppb

94FE0837C Tokyo KAGAKU KOGYO NIPPO in Japanese 28 Jun 94 p 1

[FBIS Translated Text] Nippon Sanso K.K., in cooperation with Professor Hideki Hiroue of Keio University, has developed a dissolved oxygen removal technology with a nitrogen bubbling method that can remove dissolved oxygen in ultra-pure water to levels of 0.2 ppb. With previous methods, dissolved oxygen concentrations of 1 ppb or less have not been achieved at a practical level. Removal efficiency is improved by controlling the fluid state of nitrogen gas bubbles within the equipment, in addition to using materials with low oxygen permeability for the equipment components. A test device is already in operation at the company's Tsukuba laboratory. Nippon Sanso plans to shed light on the particulars of the mechanism, and intends to commercialize the technology for ultra-pure water manufacturing equipment for 256 megabit chips.

The ultra-pure water used for cleaning in the LSI manufacturing process needs to be even more pure as LSI circuits become more highly integrated. This is because the oxygen dissolved in ultra-pure water forms a natural oxide film on the wafer surface and produced adverse effects, such as causing the silicon to elute into the water.

The concentration of dissolved oxygen must be reduced to 1 ppb or less for 64 and 256 megabit chips, but the film degassing method and nitrogen bubbling method that are now widely used have critical flaws; not only is it difficult to achieve the needed concentrations, but at times the concentration of other impurities, such as organic carbon, increases.

Until now, the speed of the moving materials and the catalytic efficiency between the nitrogen gas and water were thought to determine the limit of dissolved oxygen removal with the nitrogen bubbling method. Nippon Sanso found that an additional factor was that once the dissolved oxygen concentration was at the ppb level, oxygen in the atmosphere permeates through the plastic parts and materials that make up the equipment and mixes with the ultra-pure water, raising the oxygen concentration.

Based on these research results, polyvinylidene fluoride (PVDF), which has low oxygen permeability, was used for equipment parts and materials. In addition, the dispersed gas tube shape was optimized so that the fluid state of the nitrogen gas bubbles has uniform bubble flow. These steps increased removal efficiency.

Nippon Sanso's method can be added to equipment in individual factories requiring ultra-pure water of the highest purity in the semiconductor manufacturing process. There have been some recent proposals regarding the removal of dissolved oxygen in ultra-pure water, such as a method that once again uses a metal catalyst, but in terms of overall contribution, including simplicity of equipment, the superiority of Nippon Sanso's new process is unrivaled. The company will develop the process for use in boiler water as well as for the semiconductor industr

Chiyoda, MHI, KHI Begin Simplified Desulfurization Project for China

94FE0837D Tokyo NIKKAN KOGYO SHIMBUN in Japanese 23 Jul 94 p 5

[FBIS Translated Text] Chiyoda Chemical Engineering and Construction Co., Ltd., Mitsubishi Heavy Industries, Ltd. (MHI) and Kawasaki Heavy Industries, Ltd. (KHI) have each begun simplified desulfurization projects for China, based on the Ministry of International Trade and Industry's (MITI) Green Aid Plan (energy and environmental improvement projects for developing countries). On the 22nd, the Engineering Association (Hideshiro Saito, Chair) announced that an agreement had been reached with China's Choju [Japanese pronunciation] Chemical Engineering Co. in Chongqing for a simplified desulfurization equipment verification project based on the Plan, and that Chiyoda would be in charge of the project; in addition to the Center for Coal Utilization, Japan has contracts with MHI and KHI. Work has already begun on the three projects, with their goal being development and dissemination of appropriate equipment that brings together Chinese capital and technology.

The three projects are part of a "Verification Project for Simplified Desulfurization Equipment," which is part of the New Energy and Industrial Technology Development Organization's (NEDO) "Clean Coal Technology Model Project" for assisting in introducing environmentally benign coal utilization systems. The Chinese State Planning Commission's Chemical Engineering Department is the agency acting as the liaison in China, and each project has a budget of approximately ¥500 million over three years.

The Engineering Association has adopted the jet bubbling desulfurization method developed by Chiyoda, which injects waste fumes into a calcium hydroxide solution and adsorbs and removes sulfur oxides SO_x. The calcium hydroxide uses by-products from Choju Chemical Engineering's processing, and the gypsum produced from the reaction with SO_x is used in cement manufacturing.

Choju creates 61,000 cubic meters of waste gas per hour with coal burning boilers. Large-scale equipment with desulfurization rates of 95 percent are used in Japan, but the desulfurization rate of the present equipment will be 70 percent; by simplifying the peripheral equipment, equipment and operating costs are reduced and operating technology is simplified. Verification operations will be performed from July 1995 to March 1996, and desulfurization performance and economy evaluations are planned.

The Center for Coal Utilization has commissioned two projects to verify simplified desulfurization technology: MHI for Ibo Chemical Engineering Works in Shandong Province, and KHI for Nanning Chemical Engineering Collective Co. in the Guangxi Zhuangzu Autonomous Region. The projects are already in the planning stage, with construction and verification tests on the same schedule as the Engineering Association project. China consumes vast quantities of coal, but only one plant has desulfurization equipment. Air pollution and acid rain caused by sulfur oxides have become a serious problem, and without any real desulfurization equipment, there are many people who want simple, low-cost desulfurization equipment, even if the desulfurization rate is lower. The goal is to verify simplified desulfurization with these three projects, and disseminate the appropriate equipment to developing countries.

Sumitomo Metal Mining Co. Develops Organochlorine Treatment System

94FE0837E Tokyo KAGAKU KOGYO NIPPO in Japanese 10 Jun 94 p 1

[FBIS Translated Text] Sumitomo Metal Mining Co. Ltd. has developed a precious metals catalyst that can almost completely separate volatile organic chlorine compounds such as trichloroethylene. The catalyst will be part of a system for soil and groundwater pollution, and Sumitomo has formally set a course for developing a business. The catalyst used carries several kinds of precious metals in a ceramics carrier, and is able to break down toxic substances nearly 100 percent, rendering them harmless; compared to currently used systems, its thermal efficiency is unsurpassed and no secondary products are produced. With the cooperation of related firms, the catalyst will operate as a system for restoring soil and groundwater to their former states, and for equipment design and execution.

The device Sumitomo developed is a platinum desulfurization catalyst that carries several kinds of precious metals in a ceramics carrier composed of aluminum oxide and zirconium. It is effective at separating and decomposing organic chlorine compounds, and in verification tests at the company's Central Research Lab (Ichikawa, Chiba Prefecture), it was confirmed that nearly 100 percent of the toxic substances were decomposed.

Compared to ordinary pyrolysis methods (900-1200°C), decomposition occurs at low temperatures of 400-500°C, and the thermal efficiency is excellent. An additional feature is that toxic secondary products are not produced by the system.

Furthermore, the new method can completely break down gases having a wide range of concentrations, from rare gas produced when cleaning up contaminated soil to the highly concentrated gas needed for direct breakdown of organic chlorine compounds no longer in use.

Groundwater and soil contamination are becoming problems in Europe and the United States, and environmental and pollution control businesses are rapidly growing as legal restrictions are tightened. These markets are expected to expand in Japan as well. For this reason Sumitomo Metal Mining, together with Sumitomo Metal Consultants, a total investment subsidiary, Sumitomo Construction Co., and Kyoyo Industrial Co. (main office Tokyo), an

industrial waste treatment firm, established a joint corporation called Sumiconseltec in May 1993. Joint work has begun on restoring contaminated groundwater and soil to their former conditions.

As for the decomposition system, the catalyst will be mass-produced at Sumitomo Metal Mining's subsidiary, N. E. Chemcat Corp., and Sumiconseltec and Sumitomo Mining Engineering will perform soil restoration and equipment design and sales, respectively.

Waseda University Develops New Catalyst to Reduce, Remove NO

94FE0837F Tokyo NIKKAN KOGYO SHIMBUN in Japanese 4 Jul 94 p 7

[FBIS Translated Text] Professor Eiichi Kikuchi of Waseda University's Science and Engineering Department and his assistant, Yoshinori Yogo, have developed a new catalyst for reducing and removing nitrogen monoxide (NO) from waste gas.

By combining platinum and other substances with an indium type zeolite catalyst, the methane in the waste gas becomes a reductant, and the catalyst can reduce without interference due to steam. Therefore, it can be used to treat the waste gas from gas engines used for cogeneration, which uses methane from municipal gas companies for fuel. The findings will be presented at the International Zeolite Conference to be held in Germany beginning on the 17th.

NO reduction takes place in power plants with a method that uses ammonia, but because ammonia is toxic, it is difficult to handle. Furthermore, the method cannot be used for diesel engines, as the waste gas contains large quantities of oxygen. Therefore, a method using a zeolite catalyst (Cu-ZMS-5) and the minute quantity of hydrocarbons in waste gas as a reductant has attracted attention.

Professor Kikuchi demonstrated that when indium was substituted for the copper (Cu) in the catalyst, a reaction occurs that changes methane into a reductant, which did not happen with the copper. And carrying metals such as platinum and indium solves the problem of the steam in the waste gas lowering catalytic activity.

The catalyst enables the methane, which is abundant in waste gas, to be used. Furthermore, it is considered practical for cogeneration, which uses municipal gas (methane) as fuel and is receiving praise as an energy conserving system that effectively heats, cools, and supplies hot water for hospitals and sports facilities.

Ishihara Sangyo Develops Method to Decompose PCB Using Titanium Oxide

94FE0837G Tokyo NIKKAN KOGYO SHIMBUN in Japanese 20 Jul 94 p 7

[FBIS Translated Text] Ishihara Sangyo Kaisha Ltd. (President Takashi Akizawa) successfully used titanium oxide for photolysis of polychlorinated biphenyl (PCB), which is difficult to decompose. The PCB was almost completely decomposed without high temperatures simply by applying light while pouring PCB into a container filled with titanium oxide. Unlike other treatment methods, harmful secondary products are not created, and the method can be carried out at a low cost by using compact equipment. There was no adequate PCB treatment method, and there were very few missing cases. The new method seems to be attracting notice as a possible winner in PCB treatment.

Ishihara Sangyo's decomposition method emits highly reactive active oxygen when the titanium oxide receives ultraviolet rays, and utilizes properties that decompose various chemical substances. The company was developing titanium oxide for photocatalysis, which breaks down weak odors and stains, but as is, this method could not deal with PCB, which is difficult to decompose. Then a special titanium oxide that was active in a rutile form, which differs from ordinary crystal forms, was prepared. The fine particles of this titanium oxide was applied to the surface of ceramics particles, and PCB in suspension was poured into a container filled with these particles while ultraviolet rays were applied. As a result, it was confirmed that the PCB almost completely decomposed into hydrogen, carbon dioxide, and chlorine.

Because the reaction takes place at room temperatures, and can be done with compact equipment, it is seen as "perhaps the definitive PCB treatment method" (Functional Materials Development Department Chief Sadao Murazawa). In the future, the company wants to examine establishing plants in cooperation with the Ministry of International Trade and Industry (MITI) and related government agencies.

PCBs were once widely used as thermal media and oil insulation, but because these cause liver functions to fail, their use was prohibited. PCB already manufactured was put into storage, but restrictions often became lax as the years went by. Temperatures of 1000°C are required to burn the chemically stable PCB, causing numerous problems such as the production of deadly dioxin as a secondary product. Appropriate treatment methods are being sought.

Secret Key Ciphers That Change the Encipherment Algorithm Under the Control of the Key

43070001A Tokyo NTT REVIEW in English Jul 94 pp 85-90

[Article by Shoji Miyaguchi, senior research engineer, supervisor, Network Information Systems Laboratory, NTT]

[FBIS Transcribed Text] *This paper outlines a design method for secure secret key ciphers whose keys resist attack, and related problems. The proposal is that the encipherment algorithms should dynamically change under the control of the encipherment key. The design method repulses attacks that calculate the encipherment key using pairs of plaintext and their ciphertext block.*

1. Changing Encipherment Algorithms

NTT uses the Fast Data Encipherment Algorithm (FEAL) cipher family in many services to ensure that the data communicated remains confidential. The FEAL family uses a parameter to specify the internal rotation number in the encipherment procedure. The key length is either 64-bit or 128-bit. Users can select an appropriate rotation number and key size by considering the tradeoff of security level against calculation overhead.

We have been continually evaluating the security of the FEAL cipher family, and have continued to study the security of secret key cipher systems in general. New theories on attacking encipherment algorithms have been developed very recently. The author feels that we cannot say that there is zero probability of finding an attack method to an open cipher if (1) the algorithm is fixed and (2) the time available to develop attack method is very long. By denying the first weakness, i.e., by designing ciphers that have no fixed encipherment algorithm the author obtained a method for designing secure ciphers whose keys resist attack. This paper outlines a design method for secure secret key ciphers, and related problems. The design concept that was first proposed by the author[1] is that *secret key encipherment algorithms should dynamically change under the control of the encipherment key.*

Note that the author assumes readers are familiar with the outline of Data Encryption Standard (DES) and FEAL ciphers, differential attack, and linear attack.

2. An Example of a Changing Encipherment Algorithm

This clause explains the idea of changing the structure of encipherment algorithms, by examining a modified DES cipher. Figure 1 shows the example of a changing encipherment algorithm, where selections of S-box internal substitutions (from S_1 to S_8) of the DES cipher are achieved under the control of the external subkey Ki, not S-box input data. However, this change leads to the following unsolved general problems:

(1) What is the security criteria for selecting the best substitutions?

(2) How to construct the f-function using both permutation(s) and/or substitution(s) controlled by the subkey. (Therefore, the modification in Fig. 1 is not a better solution as a counter measure against attack.)

3. Differential Filter To Change Encipherment Algorithm

Paper[1] proposed a differential filter and a quasi-differential filter as processing elements of ciphers to change the structure of DES-like ciphers. (Quasi-) Differential filters are used to block differentials which are used by differential attacks. (Quasi-) Differential filter is one-to-one mapping, and can change the structure of a cipher under the control of the encipherment key.

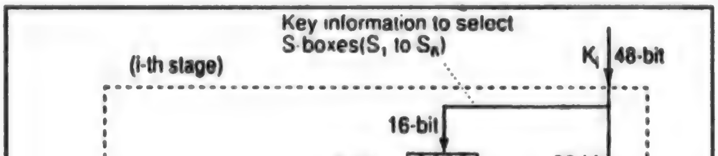

Figure 1. An Example of DES's f-Function Modification With the Idea That Substitution Tables (s-Boxes) Are Selected With Key Information Ki (but not a better solution)

3.1 Differential and Quasi-Differential Filters

Define input differential x' as $x' = x\ (+)\ x^*$ and output differential y' as $y' = y\ (+)\ y^* = g\ (x)\ (+)\ g\ (x^*)$ for a given function $y = g\ (x)$, a zero differential φ is defined as $\varphi = 000 \ldots 0$.

Definition 1: Differential Filter

Define the *differential filter* $y = \Psi\ (x, \lambda)$ as a one-to-one mapping for any given parameter λ and that y'_a *is not equal to* y'_b when *a is not equal to b*,

where $y'_a = \Psi\ (x_1, a)\ (+)\ \Psi\ (x^*_1, a)$, $y'_b = \Psi\ (x_2, b)\ (+)\ \Psi\ (x^*_2, b)$, and x_1, x^*_1, x_2, x^*_2 can be all possible values that satisfy $x_1\ (+)\ x^*_1 = x_2\ (+)\ x^*_2$ is not equal to φ. (see Fig. 2)

Note: only distinct values of λ are allowed (e.g., odd numbers)

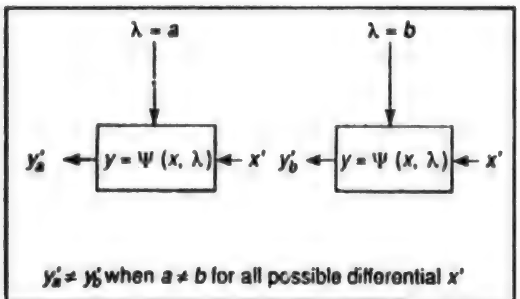

Figure 2. Differential Filter

By contraposition of the above definition, we have:

Lemma 1: Differential Filter

Let function $y = \Psi\ (x, \lambda)$ be a differential filter and y'_a, y'_b, as defined above. If $y'_a = y'_b$ for all values x_1, x^*_1, x_2, x^*_2, such that $x_1\ (+)\ x^*_1 = x_2\ (+)\ x^*_2$ is not equal to φ, then $a = b$.

Definition 2: Complexity of Differential Filter

Define the *complexity* of the differential filter Ψ as the number of cases where parameter λ can be any value. When λ is m-bits long and $0 \leq \varphi \leq 2^m$ then complexity C is $C = 2^m$.

The effectiveness of the proposed differential filter can be stated as the following lemma.

Lemma 2: Success Probability of Input Differential

If a differential filter Ψ is openly known but its parameter λ is kept secret, then an input differential into Ψ can only output its pre-expected value of output differential with success probability of $1/C$.

Definition 3: Quasi-Differential Filter

Define the *quasi-differential* filter $y = \Psi\ (x, \lambda)$ as a one-to-one mapping for any given parameter λ and that y'_a *is not equal to* y'_b when *a is not equal to b*, where $y'_a = \Psi\ (x_1, a)\ (+)\ \Psi\ (x^*_1, a)$, $y'_b = \Psi\ (x_2, b)\ (+)\ \Psi\ (x^*_2, b)$, and x_1, x^*_1, x_2, x^*_2 can be *almost all* possible values that satisfy $x_1\ (+)\ x^*_1 = x_2\ (+)\ x^*_2$ is not equal to φ.

Almost all reflects the probability that if *a is not equal to b* then $y_a = y_b$, occurs with extremely negligible probability.

3.2 Examples of Quasi-Differential Filters

Examples of quasi-differential filters are described, where input/output block size is N bits and $N = 2^d$ for some integer d.

Definition 4: Data Rotation Function (RT)

Data rotation function $y = RT\ (x, \lambda)$ left rotates input data block x with , which is a parameter of this function. λ can have a discrete integer value, and both x, y are N bits. Such rotation function can be realized by a left-rotation register.

Definition 5: Complexity of Data Rotation Function

Define the *complexity* of the data rotation function $y = RT\ (x,)$ as the number of cases where parameter λ can be any value.

Example 1: $N = 32$, λ is 5-bits long, and $0 < \lambda < 32$. Complexity of this RT is 32.

Example 2: $N = 32$, possible values of λ are limited to only 0, 8, 16, 24. Complexity of this RT is only 4.

Theorem 1: The data rotation function $y = RT\ (x,)$ is a quasi-differential filter. More precisely, if *a is not equal to b*, then the probability that y'_a equals y'_b is $2^{-N/2}$ over $N-1$, where both x, y and $N = 2^d$ bits, $y'_a = RT\ (x_1, a)\ (+)\ RT\ (x^*_1, a)$ and $y'_b = RT\ (x_2, b)\ (+)\ RT\ (x^*_2, b)$ satisfying $x_1\ (+)\ x^*_1 = x_2\ (+)\ x^*_2$ *is not equal to* .

Proof

It is clear that the data rotation function RT is one-to-one mapping when λ is constant. Now, since the data rotation function is linear with respect to exclusive-or operations, the equation below holds:

$RT\ (x,)\ (+)\ RT\ (x^*, \lambda) = RT\ (x\ (+)\ x^*, \lambda)$.

Let $x' = x_1\ (+)\ x^*_1 = x_2\ (+)\ x^*_2$, then we have: $y'_a = y_1\ (+)\ y^*_1 = RT\ (x_1, a)\ (+)\ RT\ (x^*_1, a) = RT\ (x', a)$.

$y'_b = y_2\ (+)\ y^*_2 = RT\ (x_2, b)\ (+)\ RT\ (x^*_2, b) = RT\ (x', b)$.

But we know that,

$y'_a = y_b\ \ RT\ (x', a)\ (+)\ RT\ (x', b) = \varphi$.

Since x' *is not equal to* φ and $a - b$ mod n *is not equal to 0*, therefore $y'_a = y'_b$ if and only if x' contains repeated patterns of length 1, 2, 4, 8..., $N/2$, where $N = 2^d$ for some positive integer d. Thus

$$\text{prob}\ (y'_a = y'_b) = \frac{\sum_{k=0}^{d-1} (2^{(2^k)} - 1) \times 2^{d-1-k}}{(2^{(2^d)} - 1) \times (2^d - 1)}$$

$$\approx \frac{2^{(2^{d-1})} \times 1}{(2^{(2^d)} - 1) \times (2^d - 1)} \approx \frac{2^{-N/2}}{N-1}$$

(Q.E.D.)

4. Dynamic Change Using a (Quasi-) Differential Filter

4.1 How To Use Differential Filter

Generate a new combined function F by connecting a (quasi-) differential filter of complexity C to the f-function (data randomization function) of a DES-like cipher, in cascade or parallel as shown in Fig. 3 for cascade connection, and in Fig. 4 for parallel. Using the combined function F, the number of encipherment procedures in one cipher stage becomes n = C times the number created by the original f-function only (see Note-1). The author assumes that the cost to calculate the encipherment key used becomes approximately n = C times for *any type of attack*, per stage. Let's call this hypothesis the *n time countermeasure against attack*. Additionally, it may be understood that the one stage built from function F can block any differential inputs with success probability of 1/C according to Lemma 2.

Note 1: There are $(2^{64}-1)$ differential inputs as i-th stage input $(L_{i-1}||R_{i-1})$ and in them there are $(2^{32} - 1)$ differential inputs where R_{i-1} is zero. $(2^{32} - 1)/(2^{64} - 1)$ is approximately zero for the calculation of the n time countermeasure.

4.2 Example of Application of (Quasi-) Differential Filter

Modify the DES cipher by adding the data rotation function, $y = \Psi(x, \lambda) = RT(x, \lambda)$, at the input of the DES f-function for cascade connection in Fig. 3 or for parallel connection in Fig. 4, where λ is defined from subkey Ki, λ = (L5 (+) R5) and '11000' where L5 is the leftmost 5 bits of Ki, and R5 is the rightmost 5 bits of Ki, and the value is 0, 8, 16, 24 (i.e., byte-wise rotation). The complexity C is 4. Consider an attack on the original DES and the modified DES, and compare the effectiveness of the data rotation function (quasi differential filter) using the following equation.

$A = n_{modified}/n_{original}$

$n_{modified}$: number of pairs of plaintext and ciphertext block needed for the modified DES

$n_{original}$: number of pairs of plaintext and ciphertext block needed for the original DES

The author assumes that A is at least 2^{30} for any type of attack, where $2^{30} = C^{16-1}$ (16: round number of DES), and

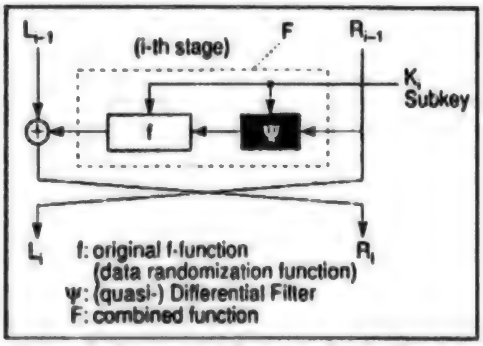

Figure 3. Proposed f-Function With (Quasi-) Differential Filter Connected in Cascade

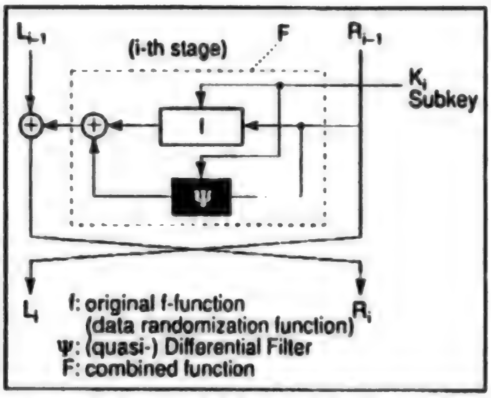

Figure 4. Proposed f-Function With (Quasi-) Differential Filter Connected in Parallel

"-1" comes from the case of non-effectiveness of the combined function F in the first stage (when $R_0 = 0$; see note-1 of clause 4.1).

5. Unsolved Problems

5.1 (Quasi-) Differential Filter

Question 1:

Find more efficient (quasi-) differential filters than the data rotation function for software and/or hardware implementation.

5.2 Use of Dynamic Substitution

Figure 5 shows an example of substitution function, y = DS (x, λ), where λ is a parameter. The function is one-to-one mapping when λ is fixed. Let's call this type of substitution, dynamic substitution (DS)[1], because the mapping is changed when λ takes other values. Other DS are described in the Annex of (1).

The differential x' (x (+) x) cannot go through the DS easily, i.e., x' is influenced by inputs (x and x*) and unknown parameter* λ. Furthermore, the DS resists replacement with effective linear approximation logic which is indispensable for linear attack[3] because there is no fixed parameter λ.

Similar DSs can be made by replacing AND logic with OR, NAND and NOR logic. The DS cannot be used directly as elements of ciphers for *the n time countermeasure against attack* (see clause 4.1). However it has the ability to change the encipherment algorithm. It is also attractive because of its easy implementation in software and hardware.

Question 2:

Connect the dynamic substitution in Fig. 5 to an f-function of DES-like cipher in parallel as shown in Fig. 6. Subkey is also used as parameter λ. Question is how secure is the modified DES-like cipher compared to the original (without DS).

Furthermore, how secure *is the cascade connection* with DS and original f-function.

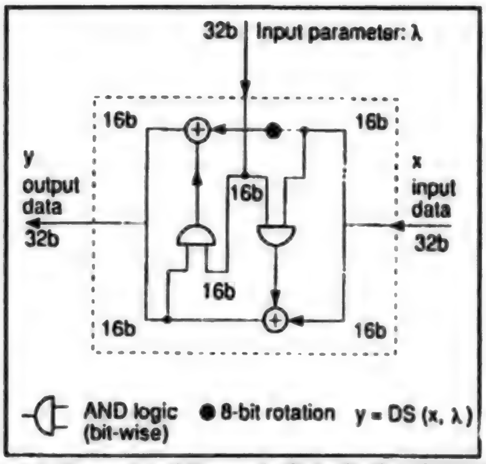

Figure 5. Example of Dynamic Substitution Controlled by a Parameter (one-to-one mapping when the parameter is fixed)

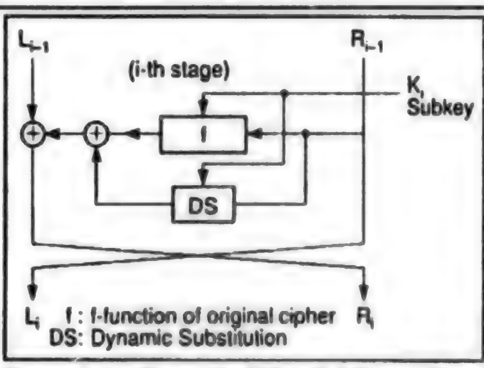

Figure 6. An Example of Parallel Connection of Dynamic Substitution

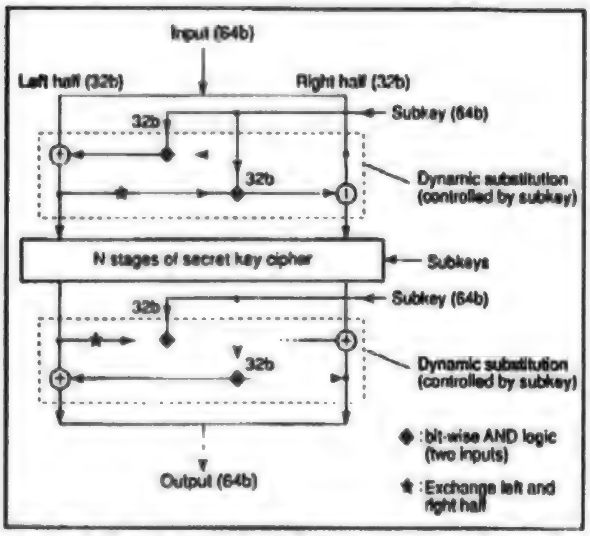

Figure 7. Example of Data Randomization of Secret Key Cipher With Dynamic Substitutions at Its Input and Output

Question 3:

Modify the input/output of FEAL-N[6] using dynamic substitutions as shown in Fig. 7. This type of dynamic substitution is made with (more than) two AND logic operations. Its output is one-to-one mapping of its input. This modification leads to low implementation cost in software/hardware. The question is how secure is the modified FEAL compared with the original. The original is described for comparison:

(A) Original Processing of the FEAL-N Cipher

Plaintext p is separated into left half L_0 and right half R_0 i.e. $p = (L_0, R_0)$.

(A-1) Entry Processing

$(L_0, R_0) = (L_0, R_0)\ (+)\ (K_N, K_{N+1}, K_{N+2}, K_{N+3})$

$(L_0, R_0) = (L_0, R_0)\ (+)\ (\varphi, L_0)$ where φ is zero block.

(A-2) N-Round Stages: Calculate the below for r from 1 to N iteratively,

$R_r = L_{r-1}\ (+)\ f\ (R_r, K_{r-1})$

$L_r = R_{r-1}$

(A-3) Exit Processing

$(R_N, L_N) = (R_N, L_N)\ (+)\ (\varphi, R_N)$

$(R_N, L_N) = (R_N, L_N)\ (+)\ (K_{N+4}, K_{N+5}, K_{N+6}, K_{N+7})$

ciphertext c is given as $c = (R_N, C_N)$

(B) Modified Processing of the FEAL-N cipher for consideration

Plaintext p is separated into left half L_0 and right half R_0, i.e., $p = (L_0, R_0)$

(B-1) Entry Processing

$(L_0, R_0) = (L_0, R_0)\ (+)\ ((R_0)\ \&\ (K_N, K_{N+1}), \varphi)$ where & is bit-wise AND logic.

$(L_0, R_0) = (L_0, R_0)\ (+)\ (\varphi, (EXG\ (L_0)\ \&\ (K_{N+2}, K_{N+3})))$, where EXG (x) is exchange of left and right half of x.

(B-2) N-Round Stages: Calculate the below for r from 1 to N iteratively,

$R_r = L_{r-1}\ (+)\ f\ (R_{r-1}, K_{r-1})$

$L_r = R_{r-1}$

(B-3) Exit Processing

$(R_N, L_N) = (R_N, L_N)\ (+)\ (\varphi, (EXG\ (R_N)\ \&\ (K_{N+4}, K_{N+5})))$

$(R_N, L_N) = (R_N, L_N)\ (+)\ ((L_N\ \&\ (K_{N+6}, K_{N+7})), \varphi)$

ciphertext c is given as $c = (R_N, C_N)$

Conclusion

This paper outlined how to design DES-like ciphers whose keys resist attack, and related problems. The proposed concept is that encipherment algorithms should not remain fixed. In more detail, they should dynamically change under the control of the encipherment key (dynamically structured secret key cryptosystems). This paper includes the basic idea of paper,[1] and considerations on recent papers[3,5] describing attacks. Paper[1] described a

design method of DES-like ciphers which resist differential attack.[2] A permutation (such as data rotation) and substitution functions whose one-to-one mapping function can be controlled by parameter appear to the author to be very useful in designing secret key ciphers that can change the structure of their encipherment algorithms. The concept that the structure of a secret key cipher algorithm changes dynamically under the control of the cipher key which creates a more secure cipher is becoming popular in Japan (as seen in paper[7]), after the publication of paper[1].

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Improved Fiber Transfer and Test System

43070001B Tokyo NTT REVIEW in English Jul 94 pp 79-84

[Article by Osamu Yamauchi, chief engineer, and Hiroatsu Matsumoto and Shinji Goto, engineers, Customer Systems Development Department, NTT: "Improved Fiber Transfer and Test System: A System that Makes It Possible To Test 160-km Optical-Fiber Long-Transmission Lines"]

[FBIS Transcribed Text] *Beginning this year, NTT will use optical-fiber amplifiers (Footnote: Optical-fiber amplifier: a combination of a sending output amplifier and a receiving low-noise pre-amplifier, erbium-doped fibers are used to amplify light waves with a length of 1.5* µm.) in module A of its synchronous digital hierarchy transmitters to double the maximum spacing between repeaters in optical-fiber lines. This will make it necessary to increase the effective length of the fiber-transfer and test system (FITAS) used to transfer and maintain optical-fiber long-transmission lines. NTT has developed a new system to address this need.

1. Background

To increase the performance and decrease the cost of optical-fiber long-transmission lines, NTT is using optical-fiber amplifier technology to double the maximum spacing between repeaters along its SMF cables (communication wavelength of 1.31 µm) from 40 to 80 km, and that for repeaters along its DSF cables (communication wavelength 1.55 µm) from 80 to 160 km. To handle this increased spacing, NTT has also increased the effective length of the FITAS used to transfer and maintain these optical-fiber long-transmission lines.

2. System Description

FITAS is an operational system that supports the construction and maintenance of optical-fiber trunk and junction transmission lines. The main functions provided by this system are automatic testing of optical fibers and the remote transfer of optical fibers, which is make possible by the use of transfer connectors (Footnote: Transfer connector: a 2 x 2 connector switch consisting of an enhanced MT connector.).

As shown in Fig. 1, FITAS consists of fiber monitor and control (FMC) equipment, fiber transfer and test module (FTTM), and fiber transfer and test equipment (FTTE). The FMC equipment consists of workstations installed at maintenance centers; they operate through a DDX-P network to remotely control all FTTE devices located within the respective maintenance area and to issue instructions to the FTTE devices for the testing and transfer of optical fibers. The FTTE and FTTM modules are located at branch offices, intermediate repeater points, and other buildings where optical-fiber cables are installed.

The FTTE modules include test equipment and transfer controllers; the controllers control all test equipment and FTTM devices located within a given building in accordance with instructions from the FMC. This is done by performing OTDR, loss, and other forms of testing and then sending the results to the FMC. One FTTE module can control a maximum of 10 FTTM modules (see Fig. 2).

The FTTM has a fiber selector for selecting the fibers to be tested. It uses an optical-fiber cable terminator to repeat and an optical branching and transfer module to transfer signals between systems and to input or output test light along the communications channels. As shown in Fig. 3, the optical branching and transfer module consists of transfer connectors, couplers (Footnote: Optical coupler: a device used to divide an optical signal traveling along a single optical fiber into multiple signals that can be transmitted over several different fibers, or to join together optical signals traveling along several different optical fibers for transmission over a single fiber.), filters (Footnote: Optical filter: a device used to process signals from a light source consisting of different wavebands so as to transmit light signals over a specific waveband while blocking the transmission of light from all other wavebands.), and other optical devices, all within a single box. The optical branching and transfer module may also be built into the FTTM in accordance with the number of optical fibers accommodated by the FTTM. An FTTM may contain a maximum of 320 optical fibers (see Fig. 4).

Since it is possible to transfer between optical fibers within the FITAS, cables can be quickly and easily removed. Cables are simultaneously switched by the transfer connectors located within a given module between the optical branching and transfer modules installed in an FTTM. Transfer controllers perform the control needed for simultaneous switching between the connectors.

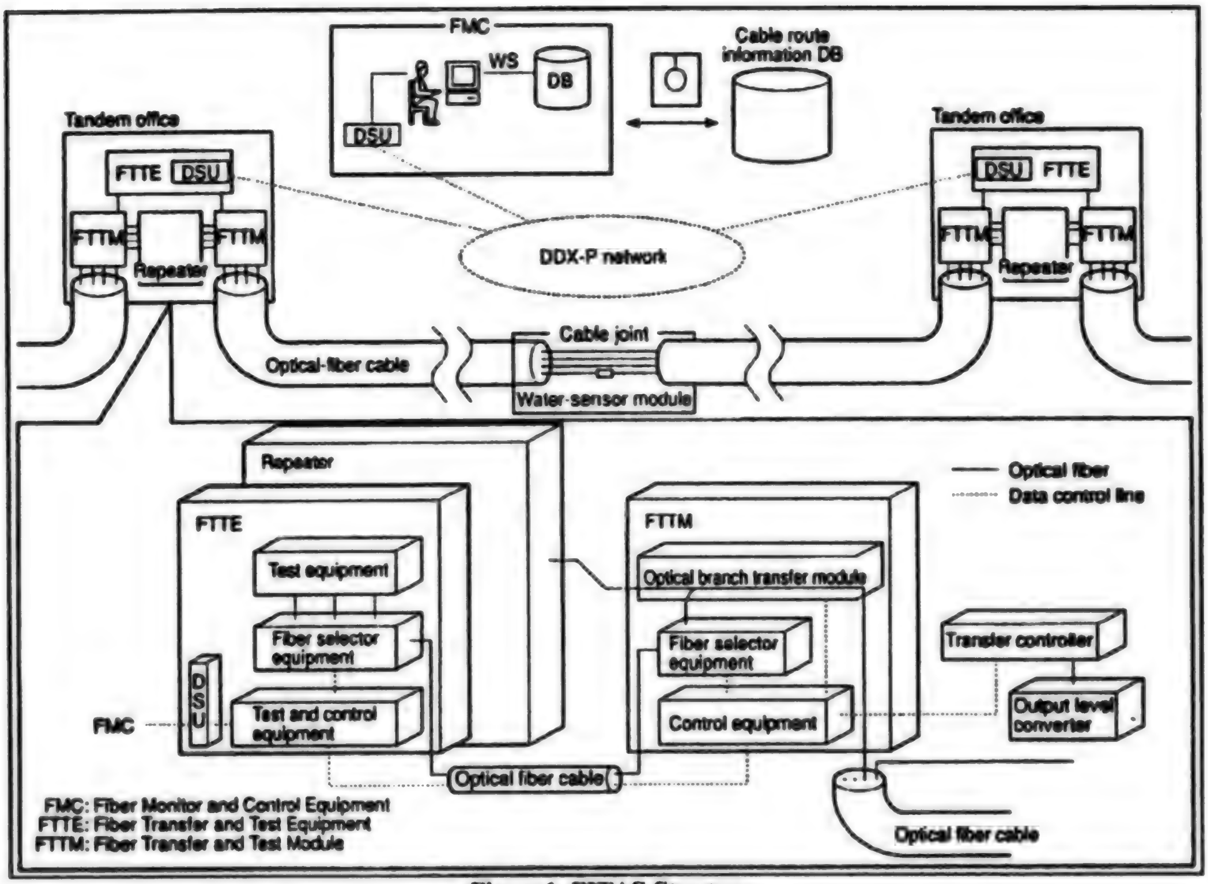


Figure 1. FITAS Structure

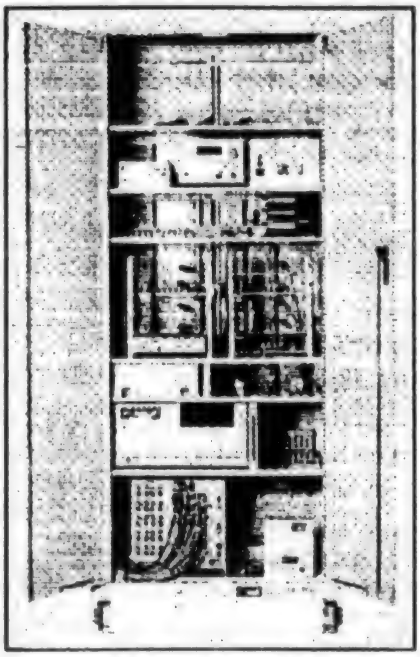


Figure 2. FTTE

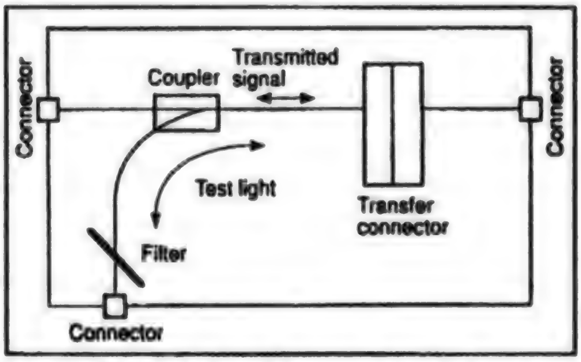


Figure 3. Optical Branch Transfer Module Structure

3. Primary Improvements

The following improvements were made to the FITAS in order to increase the spacing between repeaters along optical transmission lines:

(1) The dynamic range of the test equipment was increased

(2) The dynamic range of the synchronization signals used during transfer between fiber lines was increased

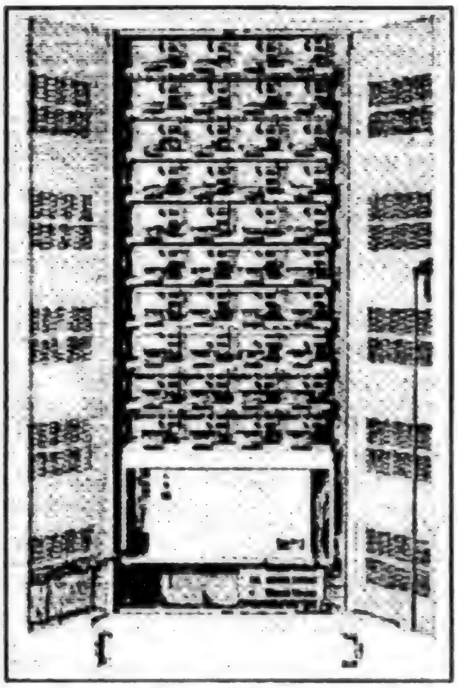


Figure 4. FTTM

The test equipment targeted for improvement includes the OTDR testing equipment used to detect optical-fiber splicing loss and to locate line faults, and the loss-testing equipment used to measure line loss.

Table 1 summarizes these improvements.

Table 1. Primary Improvements to FITAS (Along DSF Cable)

Device	Improvement made	Conventional	Long spanned
	Distance	80 km	160 km
Loss testing equipment	Testing wavelength	1.31 μm	1.65 μm
OTDR	Dynamic range (1 μs)	24.0 dB	32.5 dB
Optical branch transfer module	Coupler	1.31/1.55 μm	1.55/1.65 μm
	Filter	1.31/1.55 μm	1.55/1.65 μm
Transfer controller (output level converter)	Increases output (dynamic range)	Over 30 dB	Over 53 dB

3.1 Improvements Made to Test Equipment

NTT has—as mentioned above—increased the maximum spacing between repeaters along SMF cables to 80 km and that between repeaters along DSF cables to 160 km. The wavelengths now used in OTDR testing are 1.31 μm for repeaters along SMF cables and 1.55 μm for repeaters along DSF cables. While the same OTDR testers used previously may still be used for testing SMF cables, their effective measuring distance is too short for DSF cables. NTT has thus increased the output of the optical light emitter to make testing possible up to a repeater spacing of 160 km.

In the regular testing of optical repeater paths a loss tester is used to measure the line loss of optical-fiber lines. Along DSF cables (communication wavelength of 1.55 μm), testing is done using a wavelength that does not interrupt data transmission. Increasing in the length of optical repeater paths, however, has made it impossible to monitor the signals between repeaters spaced at the maximum distance of 160 km, even if the output level of the test pulses is raised to as high as 1.31 μm. A new test wavelength was thus required. In selecting this new test wavelength, we considered the following requirements:

(1) To test longer optical-fiber lines, a wavelength with comparatively low optical fiber loss must be used.

(2) Since testing must be performed on fiber in-service, the wavelength chosen must not affect communications or the transmission quality.

(3) The wavelength chosen must be more easily detectable than the communications wavelength in order to detect line errors.

For DSF cables, the wavelengths must be between 1.43 and 1.67 μm in order to meet the first requirement. The wavelengths must not be 1.55 μm in order to meet the second requirement. Wavelengths of 1.45 and 1.65 μm are therefore available. Since a wavelength of 1.65 μm makes it easier to detect increased loss due to bending of the optical fiber and to detect generation of hydrogen due to water seepage or other problems, 1.65 μm was chosen as the wavelength to be used for testing. A 1.65-μm light source was thus added to the loss testers, and the power meters were modified to receive light at a wavelength of 1.65 μm.

3.2 Improvements Made to Optical Branch Transfer Module

Couplers and filters are used in the optical branch transfer module to input the signal and test the wavelengths. Since a 1.65-μm light source was added to the loss testers for the DSF cables in order to handle the increased distances, the couplers and filters within the transfer module must also be able to handle wavelengths of 1.65 μ n. Fig. 5 shows the wavelength characteristics within the coupler; Fig. 6 shows those of the filter.

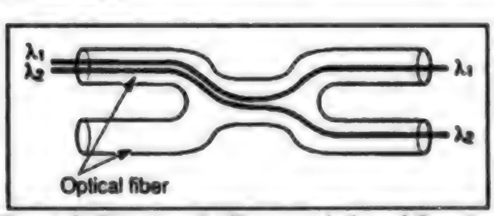


Figure 5. Wavelength Characteristics of Coupler

In the past, couplers combined waves with lengths of 1.55 μm (λ_1) and 1.31 μm (λ_2), i.e., in wavelength intervals of approximately 0.24 μm. The increased distance, however, has led to the use of test wavelengths of 1.65 μm (λ_2),

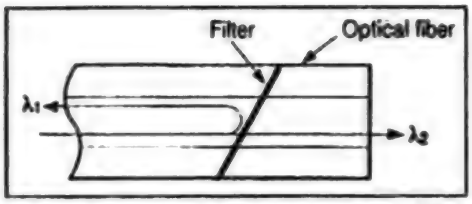


Figure 6. Wavelength Characteristics of Filter

reducing the wavelength interval with respect to the communication wavelength to 0.1 μm, or less than half of what it had been before. Improved coupler manufacturing technologies, however, have made it possible to produce compound waves at wavelength intervals of approximately 0.1 μm.

When testing fibers during communication, filters are used that allow light at the conventional test wavelength of 1.31 μm (λ_2) to pass and block light at the communications wavelength of 1.55 μm λ_1). This prevents communications waves from entering the light receptor of the loss tester, which would affect measurement of the test waves. While the normal wavelength interval between communications and test waves is approximately 0.24 μm, using a 1.65 μm wavelength for the test waves results in an interval of 0.1 μm, the same as for the coupler. Using a filter which satisfies the transmission/blockage characteristics found at this wavelength interval has made it possible to block waves at a length of 1.55 μm (λ_1) and to transmit waves at a length of 1.65 μm (λ_2) with minimal loss. This use of these couplers and filters makes it possible to test fiber lines through the optical branch transfer module (see Fig.7 [not reproduced]).

3.3 Changes in Testing Methods

FITAS testing was formerly performed by creating upper-level centers and lower-level centers for each optical-fiber cable. The use of optical-fiber amplifiers has strengthened the transmitter light output making it possible to generate light of the same bandwidth as the test wavelength (1.65 μm) through the stimulated Raman effect (Footnote: Stimulated Raman effect: a phenomenon in which excited light waves, all of the same phase, that are beamed onto a solid surface with a scatter, producing light (i.e., emitted light) of a wavelength different from that of the original light waves.). Emitting test light pulses from the upper-level center for each cable, as is done in the conventional method, thus results in fluctuations of the test light level at the lower-level center. This is why NTT has created a testing method in which loss can be accurately measured by aligning the direction of the communications and test waves generated for each fiber.

3.4 Development of an Output Level Converter

To rapidly transfer between fibers while communications are in progress, FITAS uses a single fiber to perform synchronous control. Since the maximum spacing between repeaters along optical-fiber long-transmission lines was formerly 80 km, and since the transmission and reception levels of transfer controllers are set with the line loss of an 80-km line in mind, the increase in maximum spacing to 160 km also creates the need to be able to handle an increased dynamic range of synchronous signals. This is why NTT has developed an output level converter capable of increasing the output of synchronous signals. This converter can be connected to existing transfer controllers, making it possible to communicate using synchronous signals over long-distance intervals. This increased output is generated by using erbium-doped fiber (EDF) (Footnote: Erbium-doped fiber: fibers which serve as an amplification medium for 1.55 μm wavelength light (erbium is a rare-earth element) quartz optical fibers containing microscopic quantities of this element are known as erbium-doped fibers.), to amplify the optical signals.

Since synchronization control is performed using a single fiber, the direction in which light waves are input is monitored in the output level converter, as shown in Fig. 8. The system has been changed so that it can distinguish between an increase in output and a simple transmission by monitoring the direction in which the light wave is input.

Furthermore, since the distance over which the light is transferred is not fixed, it is also necessary to change the degree to which output is increased in accordance with the distance. We therefore provided this system with a two-level amplification feature that is capable of handling transmission distances of around 120 and 160 km (see Fig. 9 [not reproduced]).

Conclusion

By using test wavelengths of 1.65 μm and by increasing the effective distance of OTDR testers and synchronized signals, it has become possible for the FITAS to monitor optical-fiber repeater lines that have increased spacing between the repeaters. NTT is now studying how we can improve maintenance of and failure prevention in optical-fiber lines.

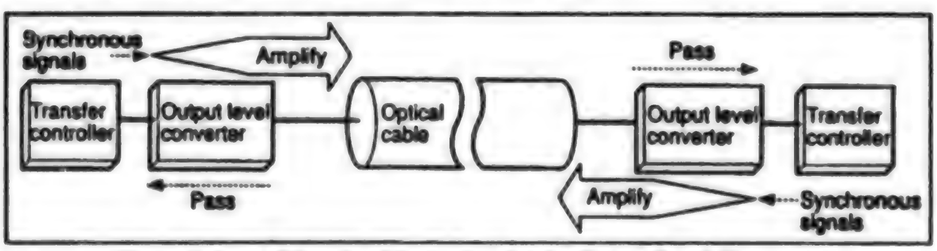


Figure 8. Input Direction Monitoring by the Output-Level Converter

Joint Utilization Tests of Multimedia Communications

43070001C Tokyo NTT REVIEW in English
Jul 94 pp 8-10

[Article by the Multimedia Planning and Promotion Office, NTT]

[FBIS Transcribed Text] *Joint utilization tests of multimedia communications were announced by NTT as part of its specific undertakings in accordance with the "NTT Basic Concept for the Coming Multimedia Age" that the company announced in January 1994. Since it began soliciting participation in the utilization test, it has received numerous applications. NTT is now discussing the contents of the tests with those applicants and is on final selection of participants.*

1. Objectives of the Tests

(1) Development and creation of new applications needed in the coming multimedia age by coordinating networks, user facilities and software.

(2) Establishment of network design and management technologies to cope with the new applications created in the above.

2. Outline of the Tests

2.1 Utilization Tests of a High-Speed, Broadband Backbone Network

NTT will conduct a nationwide utilization test over a high-speed, broadband backbone network operating at the gigabit level, using a combination of ATM and optical fiber technologies.

(1) Test of High-Speed Computer Communications (Fig. 1)

Tests of high-speed computer communications will be conducted using a 156 Mbit/s user-network interface, and will cover both high-speed inter-LAN communication and large-capacity file transfer.

(2) Tests of Multimedia Services Designed for Private Use (Fig. 2)

These tests will target multimedia information communications for private use, including high-performance E-mail and various database services, such as electronic newspapers.

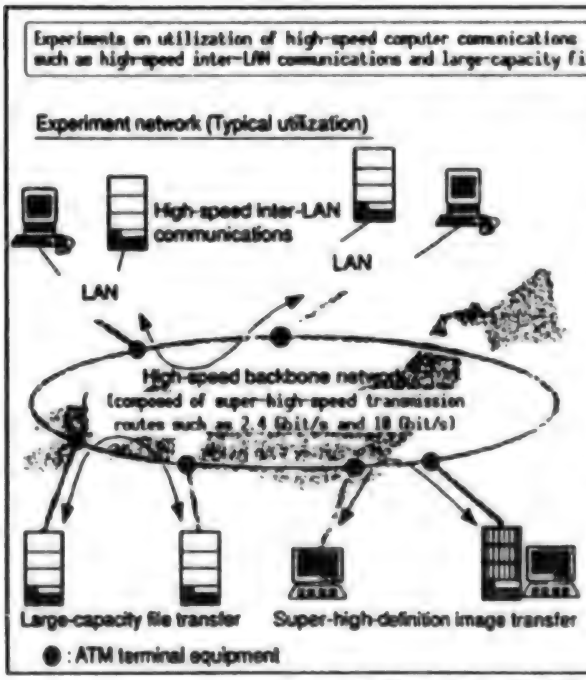
Other details of the joint utilization tests will be decided through discussions with the participants, who are expected to contribute new ideas and help develop new applications through collaboration with NTT.

2.2 Utilization Test of CATV Video Transmission and Others (Fig. 3)

In cooperation with CATV companies, NTT will conduct combined tests of CATV video transmission, Video-on-Demand, telephone and other services through optical subscriber systems as video communication services for private homes. Testing areas will be fixed through discussions with participants from CATV companies.

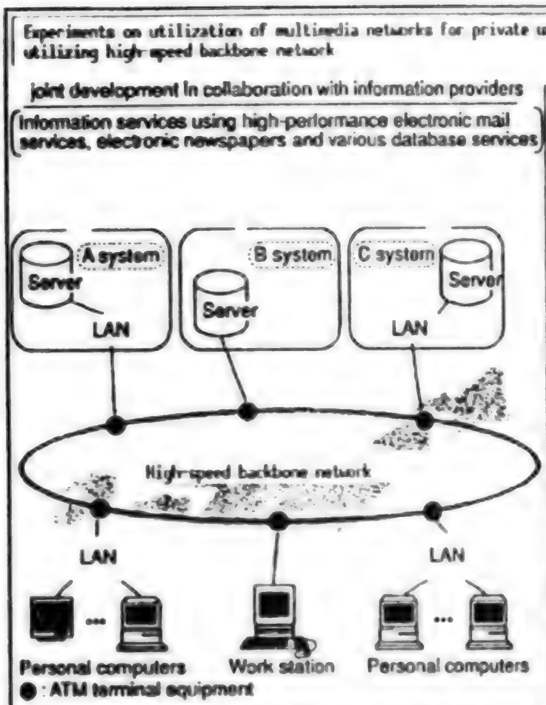
2.3 Schedule

NTT plans to determine test partners and other details about the middle of July and start the utilization test of high-speed computer communications at the end of September 1994. The other tests are expected to start next spring.



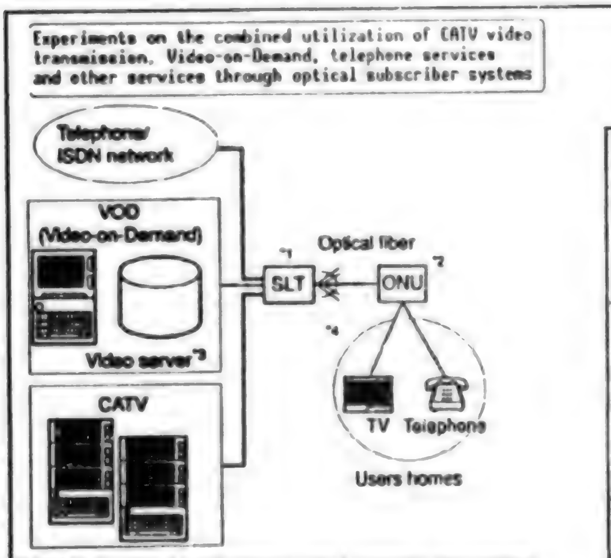
Standard for circuits provided	156Mbit/s
Participants in joint tests	Corporate and public research institutes (approximately 10 users)
Testing areas	Sapporo, Sendai, Tokyo, Nagano, Kanazawa, Nagoya, Osaka, Hiroshima, Matsuyama and Fukuoka (10 cities where terminal equipment is located) Note: Participation from other cities and areas neighboring the above cities may be considered if access transmission routes are provided at the participant's cost
Costs	• Cost of the network will be borne by NTT • Cost of the user equipment will be borne by test participants
Testing period	From the end of September 1994 to the end of March 1997 (planned)

Figure 1. Utilization of High-Speed Computer Communications



Standard for circuits provided	Several speeds will be provided according to specific applications (Up to 156 Mbit/s)
Participants in joint tests	Information providers desiring to develop new applications Note: Participation must be as a system including private users (Several hundred access circuits are scheduled to be used in total)
Testing areas	Sapporo, Sendai, Tokyo, Nagano, Kanazawa, Nagoya, Osaka, Hiroshima, Matsuyama and Fukuoka (10 cities where terminal equipment is located) Note: Participation from other cities and areas neighboring the above cities may be considered if access transmission routes are provided at the participant's cost
Costs	• Cost of the network will be borne by NTT • Cost of the user equipment (such as center equipment, application software, personal computers, connecting devices) will be borne by test participants. (In case of joint development with NTT, costs will be shared by both parties.)
Testing period	From the spring of 1995 to the end of March 1997 (planned)

Figure 2. Utilization Test of Multimedia Services Designed for Private Use



Standard for circuits provided	• Video transmission and other functions based on the optical subscriber method (Passive Double Star Method*), including telephone services utilizing INS-Net 64. *Lines diverge from the NTT service office to connect multiple subscribers, as is done for water or gas supply.
Participants in joint tests (CATV operators)	• Conducted based on offerings from CATV operators • Conducts as a complex experiment with "Video-on-Demand" (VOD) • CATV operators can select subscribers, but final selection will be made jointly with NTT based on NTT's available facilities (approximately 300–500 subscribers per area)
Testing areas	City-type CATV service areas (approximately 1–3 places)
Costs	• NTT will bear the costs for networks (However, average telephone rates will be applied when ISDN networks are utilized) • Cost of user equipment (VOD server and set top) will be borne by test participants (Cost of user equipment provided by NTT will also will be borne by the participants)
Testing period	• From the spring of 1995 to March 31, 1997 (planned)
Other	• CATV operators will procure software to be provided through CATV and VOD

*1 SLT (Subscriber Line Terminal: optical subscriber line terminal equipment)
This product is utilized to convert, multiplex and separate electrical and optical signals in the NTT networks. One unit can handle multiple subscribers.

*2 ONU (Optical Network Unit: optical subscriber line network equipment)
This product converts optical and electrical signals at a subscriber's home. One product is required at each subscriber.

*3 Video Server: Video image storage equipment that stores video and other image data and processes transmissions and other functions in line with customers' requests.

*4 Set Top: This equipment is utilized to control the selection of processes required by customers and the transmission/reception of video and/or requested data, etc.

Figure 3. Utilization Test of CATV Video Transmission and Other Technologies

3. For Further Information

Multimedia Planning and Promotion Office, Nippon Telegraph and Telephone Corporation

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Plans for an Optical Access Network

43070001D Tokyo NTT REVIEW in English Jul 94 pp 11-18

[Article by Hiroshi Ishihara, senior vice president and executive manager, Planning Department, Service Engineering Headquarters, NTT. This paper is based on a lecture given at the "NTT International Symposium 93"]

[FBIS Transcribed Text] *NTT expects demands for telecommunications in the Information Age to evolve in the direction of Visual, Intelligent and Personal (VI&P) services. In order to meet the performance needs, NTT has been promoting digitalization of the trunk network. Attention must also be paid to the access network, made up of an enormous amount of metallic cable. NTT plans to upgrade this part of the network mainly by introducing optical fiber cable, which has ample capacity to meet future service needs. Decisions must be made as to the kinds of optical systems to be introduced, from what areas, how and at what speed to proceed with this major undertaking. This article describes the present state of the access network and some of the specific approaches being taken to promote optical fiberization.*

Introduction

Traditionally, telecommunications networks have existed primarily to provide telephone and leased line services which can be handled adequately by a narrowband analog network. Advances in semiconductors and other technologies, however, have led to the emergence of digital communications terminals, which are now enjoying rapid growth. Technical progress has further made available super-high-speed microchips and large-capacity CD-ROMs at low cost. These and other developments are boosting the functional and performance levels of communications terminals, in turn creating a need for major improvements in telecommunications networks. NTT's VI&P service vision for the 21st century foresees a trend toward services that are more visual, intelligent, and personal; and this is precisely the direction in which the industry is headed, at an ever accelerating pace.

To meet such demands, the effort to transform the analog trunk network into a digital one has been under way for the past several years, and is nearing its goal. The access network, meanwhile, is still in need of a major overhaul to realize digital and broadband capabilities. Introducing optical fiber cable into this part of the network is seen as a fundamental strategy enabling it to meet the changing service needs of the future. Before this massive undertaking can be carried out in earnest, a thorough investigation must be made to determine the kinds of systems to be introduced, from what areas to proceed, how and at what speed. We have therefore begun studying management methods as groundwork for realizing an efficient optical network. These methods are based on a subdivision of the existing subscriber areas into smaller units called fixed distribution blocks. At the same time, trials have been started in which optical access systems (such as CT-RT and LD-SLT) are introduced that are able to provide optical fiber cable economically, by adopting multiplexed transmission of existing analog, narrowband services.

Although future technological developments or market changes may result in shifts along the way to optical fiberization, long-term plans call for the realization of fiber-to-the-home nationwide by the year 2015. To that end, studies have already been made on the actual methods and timing for carrying out this plan. This article details the specific approaches being taken, based on those studies, to realize an optical access network in Japan.

1. Telecommunications

1.1 Services

To help understand the present state and future plans for the access network, we will begin by looking at the kinds of services presently offered by NTT. Figure 1 shows the main network services provided, and the number of subscribers to each as of March 1993. It is clear that the vast majority of services are still analog at this point, including 57 million telephone subscribers. At one time, telephone subscribers were being added at an annual pace of more than 2 million lines. A slow economy and other factors have lowered this growth rate, but the annual demand still exceeds 1.3 million lines, requiring a substantial investment in equipment even today.

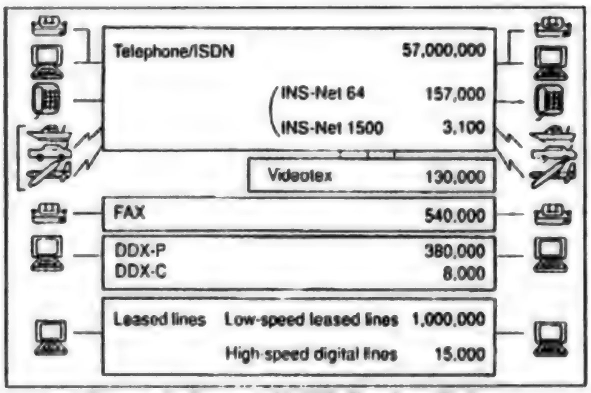


Figure 1. Status of NTT Services Today

Compared to analog services, digital services still account for only a small fraction of overall demand. Nonetheless, the demand for ISDN service, first introduced in 1988, has continued to spiral upward, increasing at the annual rate of 70,000 lines in 1992 alone. For this reason digital switches and transmission systems are being introduced at a feverish pace to meet the rising needs. The access network, however, still consists largely of metallic cable, which is unable to handle advanced digital services. Accordingly, a carefully planned strategy is necessary for digitalizing this part of the network as well.

1.2 Network Facilities

Over the past several years NTT has made an aggressive effort to digitalize and otherwise upgrade its network

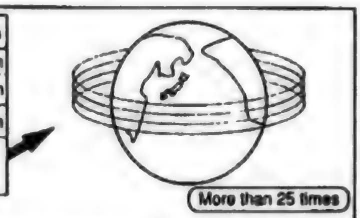
facilities. This work is nearing completion in the case of the trunk network. First of all, the twisted pair or coaxial cable running between switching systems is being replaced with optical fiber cable. On trunk routes alone, approximately 36,000 km of fiber cable has been installed as of the end of fiscal 1993. When the subsidiary routes are added, the total length reaches around 73,000 km. This part of the effort is basically complete, apart from some additional installation of optical fiber cable to enhance reliability and to meet future traffic increases.

The digitalization of toll switching systems is likewise complete, with all of these switches having been replaced by D60 digital switches as of the end of fiscal 1993. The trunk network can therefore now be considered as 100 percent digital.

Investment in digitalization is now being concentrated on local switching systems, with upwards of ¥500 billion being spent this fiscal year alone. Until recently, crossbar switches with wired-logic control systems were the rule; but these are limited in their ability to handle new services with special billing requirements, not to mention the growing number of digital services. Nationwide, they are thus being replaced with digital switches. During fiscal 1993 more than 8 million lines worth of digital switching capacity was installed, of which around a million lines were to meet demand increases, with the remaining 7 million lines consisting of replacement capacity for existing analog switches. Digitalization is proceeding at about the same pace during the present fiscal year, so that by the end of March 1995 the interim goal of changing over to stored program control (SPC) will have been achieved. This will facilitate the provision of services with various billing schemes, and should lead to a more diverse service menu, causing service competition to heat up further. Even then, some analog-type D10 switches will remain in use, making it necessary to continue the drive toward digitalization, with the goal of completing the transition by the end of fiscal 1997. Digitalization will also make possible many kinds of new services, as a result of which we can expect the focus of competition among carriers to shift from rates to service contents.

The access network, which is the main theme of this article, consists almost entirely of metallic cable at this point. As shown in Fig. 2, the amount of subscriber cable in use today is enormous. Of underground cable, the length of paper insulated cable is approximately 100,000 km, while that of polyethylene insulated cable is around 50,000 km. In other words, two-thirds of this cable is still paper insulated, which is not well suited to providing the transmission quality required for digital services. Plans must therefore be put into effect to upgrade this part of the access network. By far the bulk of the access network is made up of aerial cable, most of which is polyethylene insulated cable, with the total length extending to 850,000 km. When this is added to underground cable the overall length of the cable in the access network exceeds a million km, enough to circle the earth more than 25 times. Even today, metallic cable is being installed at the rate of 10,000 km per year to meet new subscriber demands. If an optical access network is to come into being, plans will need to be put into action as soon as possible.

	Cable type	Total length
Under-ground	PB/ST	100,000 km
	PEC	50,000 km
Aerial	CCP,etc	850,000 km
Grand-total	1,000,000 km	



PB: Pb sheath cable
ST: Steel Aluminium polyethylene sheath cable
PEC: Color coded formed polyethylene insulated conductor cable
CCP: Color coded polyethylene cable

Figure 2. Subscriber Cable Length and Types

1.3 Trends in Network Facilities Provision

Figure 3 is an attempt to summarize in one illustration the progress taking place in digitalization of network facilities.

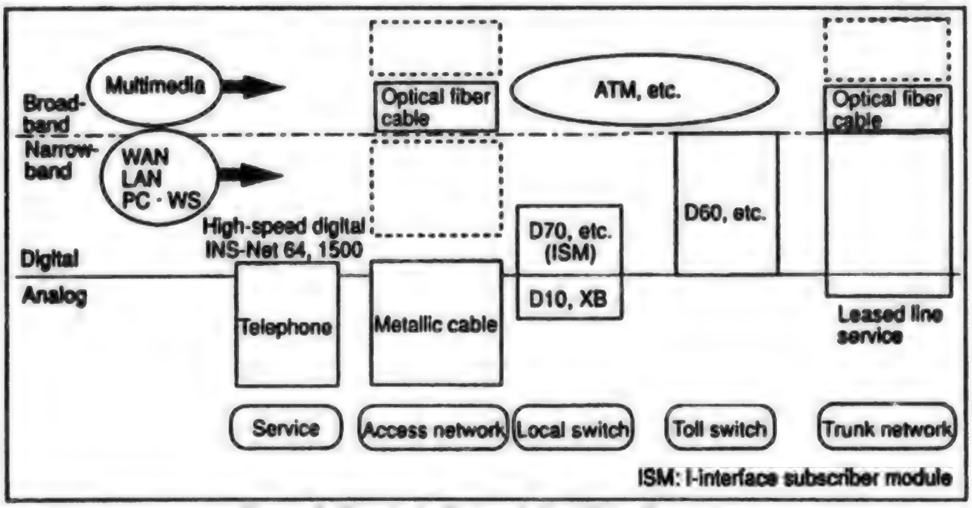


Figure 3. Trends in Network Facilities Provision

It shows that virtually 100 percent of transmission cable and toll-switching systems are now digital, and that the transition to all-digital local switches is scheduled for completion relatively soon, by the end of fiscal 1997 (end of March 1998). From this perspective, it is clear that the access network is well behind this pace. Given that many years and a great deal of capital will need to be invested in digitalizing the access network, a key point will be to carry out this effort while closely watching developments on the service front. That is, the infrastructure provisioning scenario will be greatly affected by forecasts of such market trends as whether analog service will continue to be the mainstream or will be largely replaced by digital services; and whether broadband services will expand significantly. We have examined these questions from many different angles, and have attempted to get a fix on coming service trends from our own original perspective; but this has increased our awareness of just how difficult it is to obtain accurate forecasts. Nonetheless, looking at industry movements and the like from a global viewpoint, one senses the possibility that multimedia and other broadband services will enjoy substantial growth in the not-so-distant future. Articles on this topic are appearing frequently in news media, and expectations are being raised by the very realistic and appealing contents of the services being talked about.

2. Position of the Access Network

2.1 The Role of a Digital Network

An increase in broadband services will have to be met by upgrading the network's ability to handle faster bit rates and wider bandwidths. The demand for such services, however, is not expected to be spread uniformly across the nation. Instead, a market analysis will need to be made for each area, so that economically sound plans for infrastructure provision can be devised based on the results.

Just what kind of network can we expect to emerge in the future? Figure 4 is a conceptual illustration of how the future network is likely to differ from today's. The network today is a mix of analog and digital technologies, but in the fairly near future the transition to an all-digital network should be completed, as we noted earlier. What will that mean to customers? The role of a digital network can be understood by comparing it to a modern domed stadium. The stadium itself is merely hardware. By itself it may attract construction engineers or others interested in its architecture; but whether or not its seats are filled with paying customers depends on the kinds of events held there. A digital network, likewise, can satisfy customers only if the contents of its service software are appealing to them.

A similar parallel can be raised between the access network and the various traffic systems (roads, trains and subways, or, in some cases, even airlines) by which visitors come to the stadium. That is, an access network is an essential means enabling customers to connect with the main network and receive its services. Unless sufficient effort is made to build up an effective access network, it will not be possible for customers to use the digital network services in large numbers. The access network consists of lines connecting NTT's buildings with the houses and other buildings where customers use the network services; and as with traffic systems, they come in many forms. They may be wireless or wired,

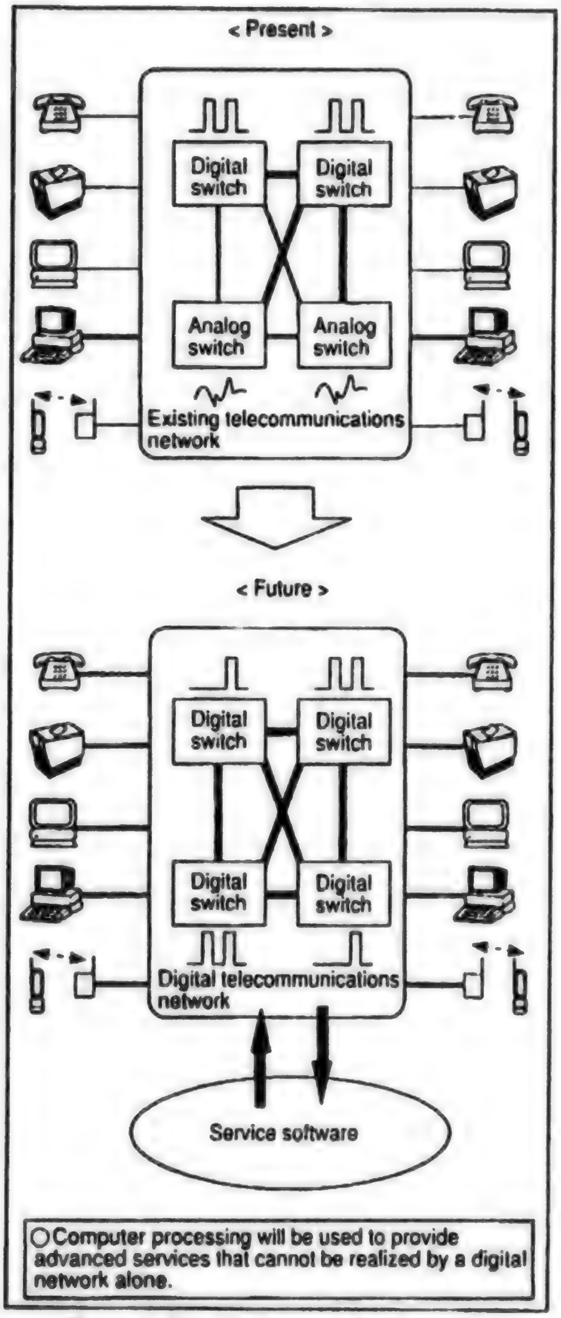


Figure 4. How the Network is Developing

and, in the latter case, there is a trend from metallic cable to optical fiber cable. The access network has the highly important role of interconnecting the user system with the trunk network on which services are provided (see Fig. 5). The way in which the access network is formed is therefore a key point. In the future this access network will become a strategic factor in terms of competition, and will likely be characterized by increasing variety.

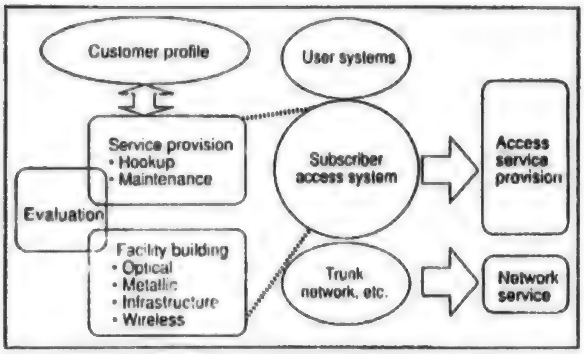


Figure 5. The Role of a Subscriber Access System

2.2 Development of the Access Network

The present form of the access network in Japan is shown in Fig. 6. Here a broad division is made between forms of access to the trunk network and the forms of the access network itself. The present forms of access to the trunk network are designed with low-speed analog services in mind, and fixed forms of user access are the rule. That is, when network access points were designed originally, this was before the age of cellular phones and other portable terminals, so only fixed access points were provided to users, whether in offices or in the home. Moreover, since the network at that time was basically metallic, a user-multiplexing approach was adopted; and there were separate lines for each service type, such as telephone service or leased circuit service. Also, because of limitations imposed by the transmission loss inherent in metallic cable, subscriber accommodation areas are relatively small, with a radius of no more than 7 km or so. In Tokyo alone there are more than 100 such areas today.

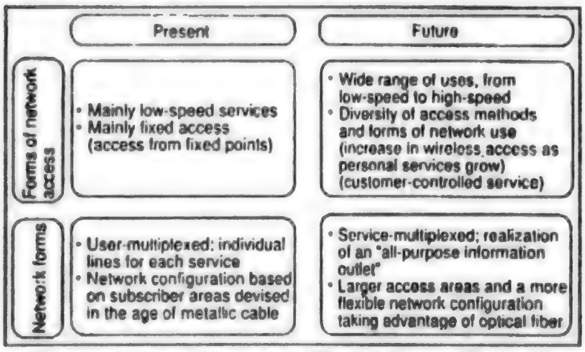


Figure 6. Transition to an Optical Access Network

As the network changes, however, the access methods are becoming more diverse. In addition to the conventional wired access system, we are seeing the emergence of wireless access systems and satellite-based systems, among others. Future developments are going in the direction of customer-controlled access, by which the user will be able to choose the access method freely. Moreover, whereas the traditional access network has been user-multiplexed, this is moving in the service-multiplexed direction. It is the large transmission capacity of optical fiber cable that is making this possible. When a service-multiplexed access system comes into being, it will become possible to configure the network more economically. For this reason the trend toward an optical access network is likely to advance at a rapid pace. With service multiplexing, it will be possible to use a single optical fiber-for-telephone, facsimile, and BBS, as well as coming video-based telecommunications services. In other words, the point at which the network connects to the user will become an all-purpose information outlet, to which terminals of all kinds can be connected freely, enabling users to take advantage of a wide variety of services. Also, the longer transmission range of optical fiber systems will provide greater flexibility in configuring accommodation areas. It is likely, for example, that existing areas will be merged into larger ones.

3. How Optical Fiberization Will Proceed

3.1 Management Based on Fixed Distribution Blocks

So far we have looked mainly at the present state of the network and at the role of the access network. Next, we will look in more detail at the questions relating to how to go about modernizing the access network. The first question is, where is the best place to begin with the task of changing over to an optical access network?

As a starting place, it is important to carry out market research, in order to discern coming trends in the market demand for broadband services. Using these results, we are working to establish a new management approach, focusing on fixed distribution blocks determined by a further subdivision of accommodation areas. The characteristics of each area are being analyzed by surveys aimed at finding out the area potential, based on the user profile, service demands and other such factors in individual blocks. On this basis the decision will be made as to which areas should be targeted for all-out introduction of optical access lines, and which areas are to be served by metallic cable for the time being.

In making such an analysis, if the unit blocks are too large or too small, this can affect the accuracy of the results on the one hand, or the efficiency on the other if too great an effort is required. The fixed distribution blocks consist of around 600 subscribers each; moreover, these are areas that have been used in the past as units for demand forecasting, as well as for facility planning. For this reason they lend themselves readily to information gathering of various kinds, and to economical facility provisioning. As a result, even at this point in time they are considered to be highly suitable management units. In the case of large customer buildings, where one building houses more than 600 subscribers and is served directly by multiple pairs of underground cable, the building is treated as one block.

3.2 Optical Access Systems

The next question to be considered is the type of system to adopt in proceeding with the transition to an optical access network. As was shown in Fig. 1, the bulk of services today are still analog and narrowband services, making it important how these are dealt with. The facility provisioning method, in other words, will differ greatly depending on whether we continue providing the services over metallic cable or include these also in the optical-fiber access

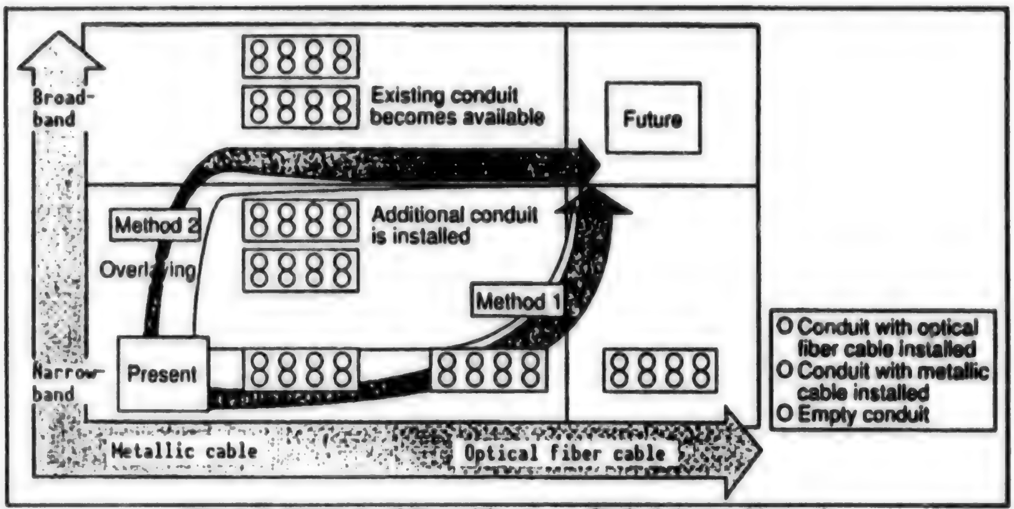


Figure 7. Methods of Transition to an Optical Access Network

system. The areas that will initially be subject to the most aggressive optical fiberization effort are the major urban centers around Tokyo, Nagoya and Osaka, as well as other urban areas judged to have a high area potential. In these heavily urbanized regions, where much of the outside plant is installed underground, and where any new civil engineering work will require a huge investment, the most economical approach to optical fiberization is one that does not generate any new civil engineering construction.

As shown in Fig. 7 as Method 1, at the same time as optical-fiber cable is deployed the existing cable is reeled in and removed. Moreover, existing conduit and the like are used while leaving room for future expansion. This approach is the most advantageous from a cost standpoint. For this reason NTT has developed optical access systems that can be used for providing existing telephone, leased line and other services, and is proceeding with the transition to an optical access network based on this method. The systems presently being used to provide optical access are a CT-RT system capable of multiplexed transmission of telephone service, and an LD-SLT system for multiplexed transmission of low speed leased line services. The CT-RT system, of which one type is for installation in the customer's building and the other is installed outdoors, accommodates between 100 and 2,000 lines. This system makes it possible to introduce an optical access system economically in relatively large customer buildings. In order to realize economical introduction of fiber access in smaller buildings, a more compact type (30 lines) is being developed for completion by the end of 1994. The LD-SLT system also comes in three types with capacities from 24 to 672 lines, and a fourth type has been developed that is integrated into the CT-RT system. This was introduced in December 1993.

3.3 Deployment of Optical Subscriber Cable

The transition to an optical access network is starting from large urban business areas where concentrated demand for high-speed and broadband services is expected. Next, the effort will move to large urban residential areas, then medium-sized urban business areas, and will gradually be expanded from there. In large urban business areas, because of the many important services provided there, a configuration like that illustrated in Fig. 8 is being adopted for the deployment of optical subscriber cable, featuring multicore optical fiber cables arranged in loops. Besides enhancing reliability, this approach improves the ability to respond to sudden demand increases. In cities located away from major urban centers, on the other hand, optical fiber cable will not only be deployed in the central business district, but also concentrated in areas of increased telephone demand such as new housing developments, industrial housing developments and the like. An economical means of deploying optical subscriber cable in this area is by use of an RT-BOX or pole-mounted RT. In remote rural areas, because of the sparse demand, use of cables with a small number of fibers is considered the most economical approach.

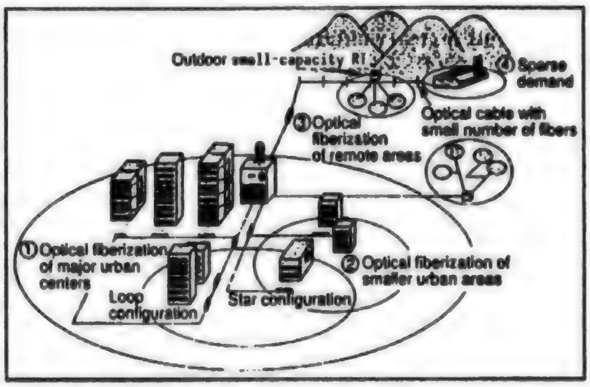


Figure 8. Optical Subscriber Cable Deployment

3.4 Facility Planning

The transition to an all-digital network will be completed by the end of fiscal 1997, after which high-speed digital

services and broadband services are expected to grow. To realize provision of these services, it will be necessary to upgrade the entire network, including the access part. NTT's plans call for achieving optical fiberization of the access network in urban areas with official city status by the year 2000. A mid-range plan for spreading this to other areas after that will be drawn up. In addition, the long-term VI&P service vision has the goal of realizing fiber-to-the-home nationwide by the year 2015. Achieving this vision will require an investment in facility upgrading over the next 20 years of approximately ¥45 trillion, if the investment in an optical access network is included. Such a huge financial outlay naturally exposes NTT to a great business risk. Nonetheless, the company intends to devote an all-out effort toward realizing this goal.

Conclusion

To conclude our discussion of how NTT is approaching the transition to an optical access network, we will look briefly at various projects under way in this connection, and consider some related issues. One such undertaking is the personal handy phone (PHP) trial service. The experiment was begun in Sapporo in October 1993, and the results obtained from it are likely to have a major impact on the provisioning of an optical access network. A second related project is the New Generation Network Pilot Model Project being planned by the Ministry of Posts and Telecommunications. From mid-1994 through 1996, this Kansai-based project will bring multimedia communications services to 300 mostly residential subscribers. In addition to existing ISDN services, the participants will have access to advanced cable TV and high-definition video services. The significance of this undertaking is that at last Japan is taking concrete steps, at the government level, to study the convergence of communications and broadcasting. We will continue to watch these developments with keen interest and high expectations.

Finally, let us examine two issues that bear importantly on the effort to realize an optical access network. The first is lowering the cost of optical access systems. When the CT-RT system is installed, for example, the floor reinforcement, air-conditioning and other additional work required in the customer's building are often as expensive as the system itself. This is a major difficulty to be overcome.

A second issue is the speed with which new services are created and user systems for providing them are developed. As the information infrastructure continues to be upgraded, the development of service software to take advantage of the increased hardware capabilities is a key factor for creating new demand. For its part NTT, in addition to its positive efforts promoting optical fiberization and creating a marketplace, is also involving itself in the development of user services and systems for their provision. It is important, however, that such efforts be carried out actively on all fronts, in order to bring us into the vaunted information age.

Optical Fiber Network Structure

43070001E Tokyo NTT REVIEW in English Jul 94 pp 19-24

[Article by Yutaka Wakui, vice president and executive manager, Telecommunications Field Systems R&D Center, NTT; This paper is based on a lecture given at the "NTT International Symposium 93"]

[FBIS Transcribed Text] *NTT is promoting the construction of an optical fiber network as an access network that can provide a variety of narrowband to broadband services both flexibly and economically. This paper describes the current deployment policy for this optical fiber network as the first step towards Fiber-To-The-Home (FTTH). The network employs a flexible and highly reliable optical fiber/optical fiber cable distribution configuration, and requires an advanced and flexible operating system to maintain and operate it. The operating system consists of various component systems and can change its own configuration. This paper describes the current state of development in optical fiber network element technology and operation technology.*

Introduction

Telecommunication services are provided by means of service networks, customer systems such as customers' terminal equipment and access networks which link them. As a result of the introduction of digital and optical transmission systems, service networks have enabled a variety of services to be supplied flexibly. There is also a growing demand from customers that their systems be made digital, high-speed, broadband, and personal. On the other hand, conventional metallic cables still account for most of the access networks, and are restricted in terms of performance when applied to high-speed and broadband services. This has resulted in an urgent call for optical fiber networks that can provide advanced and diversified services flexibly. This paper outlines the structure of the optical fiber network and describes trends in network element technology.

1. Optical Fiber Network

The optical fiber network structure can be stratified, as shown in Fig. 1, into a transmission system layer, an optical fiber layer, an optical fiber cable/conduit layer, and an operation system layer. The transmission system layer contains systems that enable various services to be supplied and provides rational interfaces for customer systems and service networks. The optical fiber layer provides optical fibers with a sufficient transparency for various broadband transmission signals. The optical fiber cable layer provides cable installation and this ensures economical and prompt access to optical fibers thus meeting geographically widespread demands. The conduit layer furnishes facilities for the flexible accommodation of optical fiber cables. The operation system layer efficiently performs such functions as network control, equipment management, and service operation.

The major functions of optical fiber networks are to ensure flexibility, economy, and reliability, and to upgrade operations. Flexibility includes the possibility of providing various services and meeting demands immediately and the capacity for expanding to meet technological advances in systems. To improve economy, it is essential to reduce not only initial costs but also running costs, and to build rational networks, while upgrading operating systems. Reliability is becoming more important because telecommunication networks are part of the social infrastructure

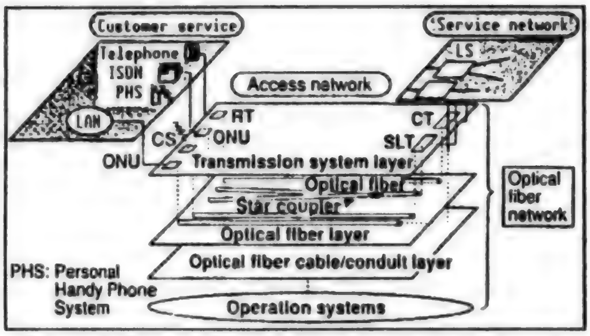


Figure 1. Optical Fiber Network as Access Network

and the demand for enhanced reliability is increasing, particularly in business areas. This requires that measures be taken to increase the reliability of network elements, promote network duplexity, and upgrade operational techniques to speed up fault repair and ensure preventive maintenance. To upgrade operational technologies, it is necessary to promote the automation and remote control of operations, and to construct an operation flow which performs service operations efficiently, while providing customer satisfaction.

2. Optical Fiber Network Deployment

Telecommunication services for business use carried through optical fibers, such as high-speed digital leased lines and primary-rate ISDN, are already being provided commercially. Although increasing in the central business areas of large cities, the demand for these services is not very high at present. Therefore, it is difficult to build efficient optical fiber networks offering the advantages of scale. Moreover such installations, if made, will aggravate the already severe congestion caused by the large number of cables in the infrastructures. These include overlays of optical fiber cables on metallic cables and the installation of additional metallic cables to meet the still emerging demand for narrowband services with analog telephones. Furthermore, metallic cables with a low transmission capacity will continue to occupy expensive conduits in large number for a long period. This will delay the planned advances in access networks.

As shown in Fig. 2, the desired progress can perhaps be achieved by promoting optical fiber transmission with a single star structure using one-to-one fiber-use systems for broadband services, and optical fiber transmission with a double-star structure using a multiplex system which can be adjusted for economical narrowband services, such as plain old telephone service (POTS) and basic-rate ISDN, and providing these two types of transmission with the same optical fiber cables. This multiplex system is called an optical access system or central terminal/remote terminal (CT/RT) system. This configuration, in which optical fiber cables are supplied to business customers' buildings is called the Fiber-To-The-Office (FTTO) and steps are being taken to make it practical. The promotion of FTTO will enable the necessary infrastructures for the growth of optical fiber transmission to be ensured. It will also allow the demand for advanced services to be promptly met, helping to build future optical fiber networks. This will go hand-in-hand with efforts to limit new or additional metallic cable installations, renew and improve aging installations and utilize existing underground facilities. Narrowband services can be supplied economically to zones remote from NTT buildings. The use of optical access systems and optical fiber installations will also be promoted for such zones. NTT has named this mode of optical fiber promotion, Fiber-To-The-Zone (FTTZ).[1]

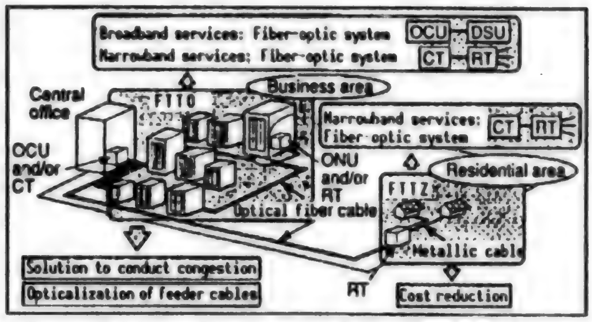


Figure 2. Current Deployment Policy of Optical Fiber Network

3. Optical Fiber Network Structure

3.1 Problems With Optical Fiber Network Structure

With FTTO and FTTZ as the first stage, NTT aims to realize FTTH as soon as possible. With this goal in mind, the company is working hard to develop attractive and useful services for the optical age, while promoting the development of transmission systems which supply services flexibly. Here it is important to provide rational interfaces between customer systems and service networks. One of the current problems is to reduce the costs of systems, including those of the optical access systems currently being introduced, and develop compact units free from environmental restrictions on their use. This makes it necessary to investigate component layouts in networks that ensure efficient and economical construction, maintenance and operation. The optical fiber layer must provide sufficient transparency to respond to the diversification of transmission systems and must function as the backbone of the network. One important problem related to the optical fiber cable layer is to establish an optical fiber distribution method. This must ensure a rapid response to demand and have the ability to handle demand fluctuations arising from various patterns of demand resulting from diversified services. The primary problem in relation to the operation system layer is to develop a system that adapts flexibly to changes in such factors as network elements, network structures, and business operation methods.

3.2 Optical Fiber Cable Distribution Method

In urban areas where a demand for advanced services is expected, the cable ring network, as shown in Fig. 3, is employed without reducing the number of optical fibers.[2] At any point in the cable ring network, optical fibers can be accessed in two ways: clockwise and counterclockwise. This offers the following two advantages:

(1) If there are any changes in the location or size of demand, these changes can be absorbed flexibly.

(2) Optical fiber can be supplied to the customer by two different routes, clockwise and counterclockwise along the cable ring. This enables reliability to be increased.

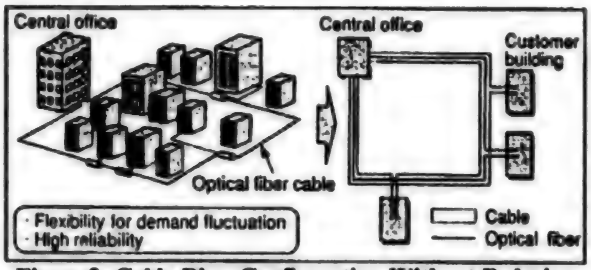


Figure 3. Cable Ring Configuration Without Reducing Number of Fibers

In a cable ring network, there are two ways to access optical fibers. One is to access the required number of optical fibers at a given point on the cable and the other is to access the optical fiber at a fixed indexed point. The first is employed in practice. Access is confined to the required optical fiber, and so this enables the number of connections to be minimized, thus permitting both connection costs and optical loss to be reduced. The important factor here is the midspan access technology needed to access the optical fiber at an intermediate point on the cable. With the second method, an optical fiber cable is laid to each fixed indexed point. This requires a large number of cables and therefore also requires a technology for laying multiple cables in one conduit and small-diameter and high-density optical fiber cables.

Cable distribution application is dependent on customer distribution. In a business area of a large city crowded with large buildings, there are many sources of demand for optical fiber and an insistence on communication reliability. Again here, it is preferable to employ a cable ring network as the customer buildings will be located near an NTT central office thus enabling a high concentration of cables to be deployed. On the outskirts of big city business areas and in the business areas of smaller cities, the buildings are smaller and the distribution more widespread. In such areas, concentrated wiring using a cable ring network is preferable in zones near NTT central offices where customers are concentrated and cable distribution, using a conventional cable star network, is preferable in zones remote from central offices because of economy. To repeat, in remote areas where customers are sparsely distributed, an optical fiber wiring using a cable star network is preferable especially in terms of economy.

3.3 Operation Systems

It is necessary to develop highly flexible operation systems that can adapt to growing optical fiber networks. For this reason, it is preferable to simplify equipment management by stratifying and grouping the operation systems into blocks in accordance with the characteristics of the network elements and to design an overall structure in which no change of system in one layer will affect any other layer. It is necessary to begin to develop the systems required to operate the transmission system and optical fiber/optical cable layers and operation systems that are suitable for services common to access networks. Figure 4 shows the future goal which is an integrated network operation system. Its three elements: modules, databases and application programs for testing, monitoring, and controlling network elements, are independent of each other and connected with interfaces via a platform for task management. This enables functions to be broken up in the operating systems, allowing them to grow independently, while permitting the resources of the modules and databases to be utilized effectively.[3] The primary problem here is to develop a database which enables data to be added or changed easily and automatically, and which provides easy access to other systems, when any change is made in the

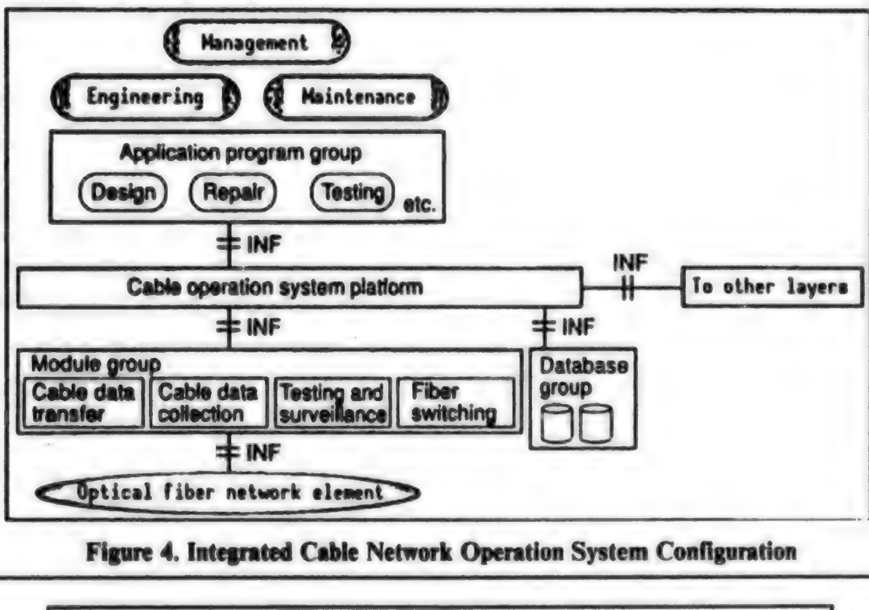


Figure 4. Integrated Cable Network Operation System Configuration

network structure. It is also beneficial for the user to be able to draw up application programs or make changes to existing ones for various operations. In the future, a module which permits network control will probably be necessary.

4. Technology for Optical Network Elements

Optical fiber cable technology is being developed to increase the fiber-density in cables so as to utilize the space in conduits efficiently and reduce costs. As shown in Fig. 5, the high-fiber-count optical fiber cable currently being introduced has optical fibers formed into ribbons and these fiber ribbons are housed in slots. The fiber density of this cable is more than five times that of cables composed of mono-coated fiber with an outer diameter of 0.9mm. A study is now being undertaken to realize a cable structure that achieves several times higher density by increasing the number of fibers in a ribbon by making the fiber coating thinner and by packing the ribbons in U-grooves.[4]

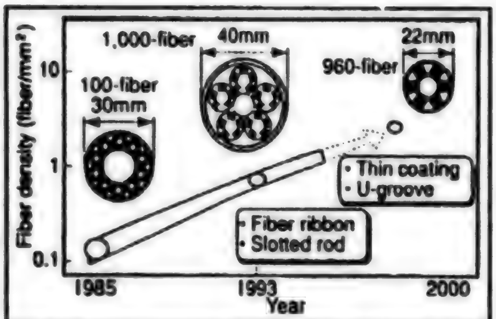


Figure 5. Development of High-Density Optical Fiber Cable

Connectors and connectorized cables are being developed to facilitate optical fiber splicing and resplicing work and to reduce the time it requires. Figure 6 shows fiber splicing workability and the insertion losses of a mono-core SC connector and a high-fiber-count MT connector, which are already in practical use. This clearly shows that it is difficult to reduce insertion losses and increase the number of fibers in a connector simultaneously. A study is under way on high-fiber-count connector technologies that ensure both low losses and high-count connectors by analyzing the causes of losses and utilizing high-precision transfer molding and shape evaluation technologies at a submicron accuracy. If a high-fiber-count cable with high-fiber-count connectors at both ends is developed on the basis of these technologies, it will certainly have a great effect on the construction and operation of the optical fiber network.[4]

5. Operation Technology

The automatic fiber operation support system (AURORA) shown in Fig. 7 is employed to test and monitor optical fiber networks. It performs tests using such devices as an optical time-domain reflectometer (OTDR), via optical couplers in a fiber termination module. The test wavelengths are different from the signal wavelengths, thus permitting in-service testing without affecting transmissions. AURORA enables optical fiber tests to be carried

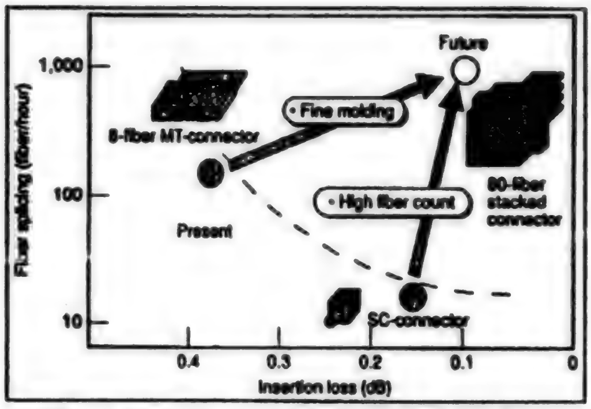


Figure 6. Development of Connector Technology

out promptly under remote control. At present, a study is underway on Brillouin spectroscopy whose aim is to enable the measurement of mechanical fiber stress distribution in optical fibers. The use of such technologies will allow optical fiber maintenance to become preventive rather than post-fault maintenance.[5]

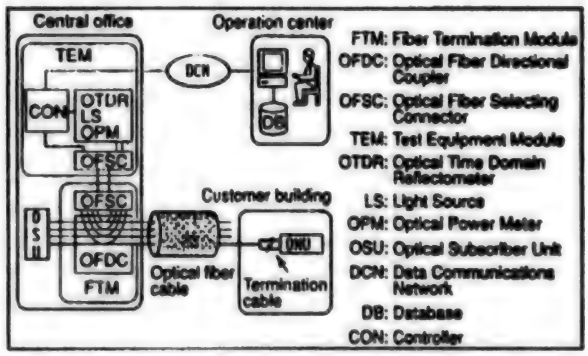


Figure 7. Automatic Fiber Operation Support System (AURORA)

One future possibility is to incorporate switching modules, developed by using optical switch technologies, in optical fiber networks. They will be capable of continuously monitoring optical fibers, thus enabling any faulty fiber route to be automatically transferred to a normal one. We already realized the technology for transferring an MT connector in less than 30 milliseconds. This ensures high quality customer service by reducing line borrowing time and reducing transfer work.[6] Furthermore, to achieve agreement between actual installation data and the data in the databases in the face of the vast amount of information which must be handled as regards fiber concatenation, another study is under way on memory connectors equipped with functions for storing and retrieving concatenation information.[7]

Conclusion

FTTH is an important R&D theme, because it can provide a wide variety of services to customers. As customers'

demands diversify, and technology advances, various systems are likely to come into use. In order to make a flexible optical fiber network practical, it is necessary to establish a network architecture based on stratification and the employment of modules. The access network, as an infrastructure, must have high reliability. For network element technologies, it is essential to reduce costs. It is also necessary to improve functions and characteristics such as high-density cable technologies, high-density fiber-splicing technologies, and technologies providing easy access to optical fibers. OA&M must be highly adaptable to changes in optical fiber networks and operations, and it is important to establish a new architecture for operating systems and develop flexible databases, easy-to-use application programs for users, and modules designed for automatic and remote-control operations.

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On the Way to Personal Communications

43070001F Tokyo NTT REVIEW in English
Jul 94 pp 59-64

[Article by Tadao Kobayashi, senior product manager, Telecommunications Services Development Department, NTT: "On the Way to Personal Communications: PHS Field Trial in Sapporo"]

[FBIS Transcribed Text] *NTT launched a Personal Handyphone System (PHS) field trial in the central business district of Sapporo on October 5, 1993. The PHS is a new service that will use the portable handsets of digital cordless phones, which are expected to be on the market before long. Users will be able to take PHS handsets with them around town to place calls at inexpensive rates. The field trial is proceeding smoothly, and many of the monitors who are participating in this experiment have been asking when PHS service will be initiated. This response has created a solid feeling that there is exceptionally strong interest in this new service. Through this six-month field trial, NTT plans to verify public acceptance of the PHS service concept and explore prospects for inaugurating service on a commercial basis.*

1. What is PHS?

NTT is proceeding with R&D work and field trials aimed at achieving its VI&P vision of 21st century communications services, which are forecast to be visual, intelligent and personal. The PHS is regarded as being the first step toward the achievement of the personal communications element in this vision of future services (Fig. 1).

Figure 1. PHS Handset

Several million cordless phones are sold in Japan every year, and the number of subscribers to car phone and portable phone services is also increasing rapidly owing to the appearance of smaller phones, among other factors. This dramatic increase in mobile phones can be seen as an expression of a desire to transcend the temporal and spatial constraints on conventional means of communication between people. In other words, it is the result of a desire to be able to communicate with other people anytime and anywhere.

Present cordless phones suffer from a spatial constraint in that they can only be used indoors. Moreover, because they are analog devices, they have the drawback of being susceptible to electronic eavesdropping. The service rates for car phones and portable phones are also high. Although subscribers of these services are increasing, their number at this point only represents a little more than one person in 100. It is clear that the attainment of true personal communications will require a good service that can strike a suitable balance among the aspects of space, time and cost. The PHS is seen as being a service that can achieve this required balance (Fig. 2).

The digital cordless phones that are expected to be released soon will provide superior speech quality and privacy. Since

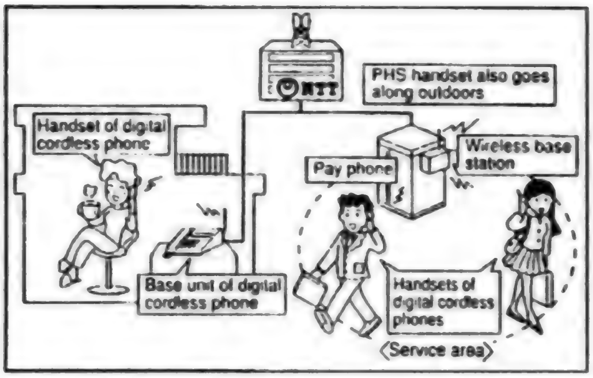

Figure 2. PHS Service Concept

PHS service will enable the portable handsets of these digital cordless phones to be used outdoors, it will be largely freed from temporal and spatial constraints. At home or in the office, digital cordless phones will be used in that form. Users will also be able to take the portable handsets outside to make and receive calls at inexpensive rates via wireless base stations, which will be installed in places having a lot of human traffic, such as business districts, shopping streets and underground malls of train stations.

Since the portable handsets will be low-power devices, similar to existing cordless phones, they will allow a more compact design than current portable phones. They will also be of much higher quality, offering a transmission capacity of 32 kbit/s, which is several times greater than that of ordinary portable phones. Moreover, they will also be able to transmit data and facsimile signals in addition to voice. However, the service area of PHS handsets will be more limited than that of car phones and portable phones. Radio waves emitted by a single PHS base station will not have the range of other cellular phone signals, which means that PHS handsets will not be usable on high-speed modes of transportation such as automobiles and trains. Basically, they will enable people to make or receive calls while walking or standing still (Table 1).

Table 1. Differences Between PHS and Car/Portable Phones

	PHS	Car/portable phones
Service area	Home, workplace, outdoors, (ex. business districts, shopping/entertainment areas, along major residential streets, underground malls, department stores, buildings, etc.)	Outdoors (wide area coverage)
Allowable speed of movement	Ordinary walking speed	Usable at high speed
Terminal	Same small to ultrasmall handset used at home, in the workplace and outdoors (transmitting power 10mW)	Small to medium-sized dedicated handset (transmitting power: approx. 1W)
Wireless base unit	Small, inexpensive	Large, expensive
Service rate	Low	High

Forecasts of the size of the PHS market vary depending on the assumptions made about the expansion of service areas, call rates and other factors. A study group organized by the Ministry of Posts and Telecommunications has made a demand forecast that suggests there will be an exceptionally large market for PHS products (Fig. 3). Assuming that PHS service is offered under the concept explained above, they estimate there will be approximately 3 million PHS users by the year 2000 and some 18 million by 2010.

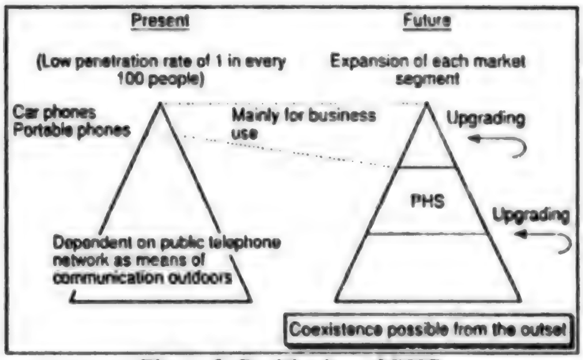

Figure 3. Positioning of PHS

2. System for PHS Service

The PHS service concept is to provide convenient portable phone service around town at inexpensive rates. To achieve this concept economically and quickly, it will be essential to utilize NTT's existing nationwide digital network rather than building a separate network anew as was done for car phone and portable phone service. This approach will also make it possible for users to enjoy the wide range of services that a digital network can support.

In preparing to conduct the Sapporo field trial, NTT added the necessary functions to the existing digital network to support the use of PHS devices. In addition, small wireless base stations and portable handsets were developed, and a system was configured for connecting PHS equipment to the public network (Fig 4). It is estimated that the use of the digital network will make it possible to inaugurate commercial PHS service at rates that are only around one-third to one-half as much as those for car phones and portable phones.

The Telecommunications Technical Advisory Council has examined a standard for the wireless interface between PHS handsets and wireless base stations. In April 1993, the Council submitted its final report on the interface standard

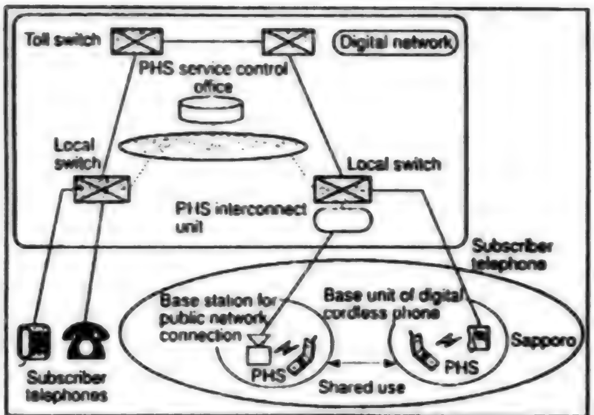

Figure 4. Configuration of Field Trial System

to the Ministry of Posts and Telecommunications. Consequently, separate from the development of the PHS business itself, equipment manufacturers will be able to put digital cordless phones on the market as soon as these products are ready to be released.

3. Field Trial Objectives

A study group was formed in October 1993 under the auspices of the Director General of the Telecommunications Bureau, Ministry of Posts and Telecommunications, to examine the practical feasibility of the PHS service concept, the issues that must be overcome in order to initiate commercial service and the specific measures that should be taken to address those issues. In June 1993, the study group issued an interim report of its findings so far. Based on that report, the Conference for Personal Handyphone System Field Trials was formed, with participation by relevant government agencies and interested organizations, including telecommunications carriers and equipment manufacturers.

The Conference decided that groups of its members would conduct independent field trials at different locations in Japan over a one-year period beginning from October 1993. The results of the field trials will then be organized and released by the Conference. Two types of field trials are to be conducted, namely, service verification tests and interconnectivity tests. The former will examine social acceptance of PHS service concept, service viability, technical aspects, users' needs and potential market size, among other factors. The latter will confirm whether PHS terminals can actually be connected to the public network via wireless equipment. The results of these tests will be reflected in the development of practical PHS products for future use. Service verification tests will be conducted by eight companies (groups), including NTT. More than 50 companies, including communications equipment manufacturers and electric appliance makers, are participating in the interconnectivity tests.

4. Overview of the Sapporo Field Trial

The field trial (service verification test) that NTT is conducting in the city of Sapporo involves some 800 monitors, who were recruited publicly and are actually using a PHS handset during the six-month period. Their opinions about the use of PHS handsets and interest in using the service in the future will be surveyed through questionnaires and group interviews. There appears to be great interest in PHS service. When advertisements were placed in newspapers and other media to recruit 800 monitors for the field trial, approximately 4,400 responses were received, more than five times the planned number. A lottery was then held to select 500 individual monitors and 300 company monitors.

Several places were designated as service areas for the field trial. One is the downtown area extending from Sapporo Station to Susukino, which encompasses the business, shopping and entertainment center of the city and includes an underground shopping mall. Another is the area around Kotoni Station, which serves the surrounding residential district. The campus of Hokkaido University, with its large student body, comprises a third area. A fourth area is the lobby of the terminal building at New Chitose Airport, the main gateway to Sapporo. Nearly all street-level and underground locations in these four areas are covered by PHS service. Spot coverage is also provided at certain places where people tend to gather, such as in the lobby of City Hall, department stores, hotel and bank lobbies, hospital waiting rooms and other indoor locations (Fig. 5).

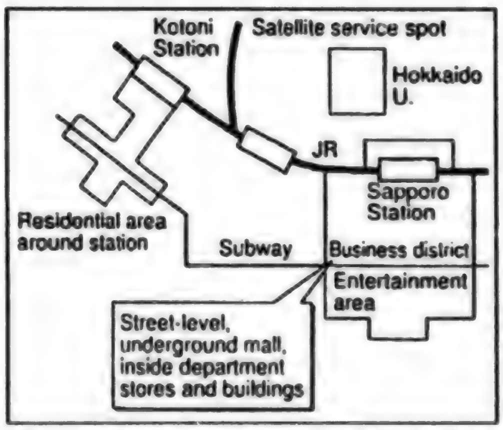

Figure 5. Service Areas in Sapporo Field Trial

The wireless base station that supports connection to the public network is compact and light enough to be carried by one person. Each station installation facilitates call service within a radius of 100-200 meters. In the Sapporo field trial, base stations have been installed on public telephone boxes, utility poles, building walls, ceilings of underground shopping malls and other places, for a total of approximately 250 installations. People can readily notice these base station installations while walking around in the service areas. At present, ordinary cellular phones cannot be used in underground shopping malls or department stores. In contrast, PHS handsets are exceptionally convenient because they can be used while strolling through an underground mall or while shopping in a department store (Fig. 6).

Among the impressions and opinions expressed by the monitors, there have been many comments in particular

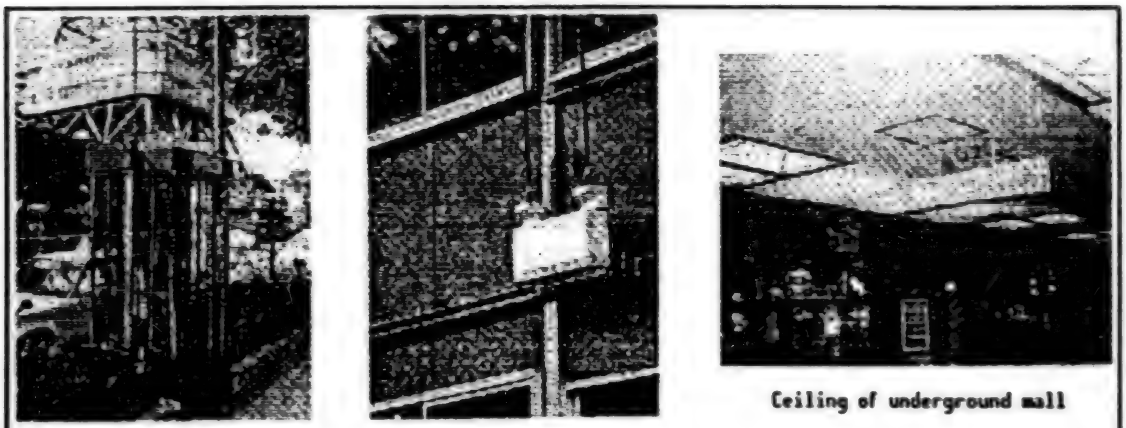

Figure 6. Wireless Base Station Installations

about the amazing speech quality and convenience of PHS service. People have remarked that the speech quality is so clear it seems like the person with whom they are talking is standing right next to them. They also like being able to take the digital PHS handset outside, enabling them to call whenever they want to. The following are some of the ways in which monitors have used PHS service effectively.

- "It was very convenient being able to complete my business without leaving my seat while sitting in a coffee shop."
- "A friend was late for an appointment; fortunately, I was able to contact the person en route and changed our meeting place."
- "While calling on a customer, there was a question I couldn't answer. Using my PHS handset, I confirmed the information and was able to reply right away."
- "I was able to confirm the appointment time en route, and avoided losing a lot of time."
- "Being able to use the PHS handset from my car during a traffic jam was really handy."
- "It's very convenient being able to call on the spot without having to search for a pay phone."
- "While calling on a customer I can make a call without borrowing their phone. That's really convenient."

On the other hand, because of the limited area of the field trial, the following opinions have also been expressed.

- "Since this is just a field trial, it can't be helped, but I hope commercial service will be provided throughout the entire Central Ward of the city."
- "I want to be able to use the PHS handset everywhere, even further inside buildings."

Some monitors have also expressed a desire to be able to use PHS handsets over a wider area and while traveling at high speed, just like ordinary car phones and portable phones. This indicates that there is ample potential for the coexistence of PHS service with cellular phones.

At any rate, based on the response so far, the PHS service concept is enthusiastically accepted by the public, and there do not appear to be any problems with service viability or technical aspects. Many monitors have indicated that they definitely want to subscribe to PHS service when it becomes available commercially if it is offered at low rates and can be used over a wider area. This suggests that there will be a rather large demand base for PHS service.

5. Future of PHS

The provision of PHS service through effective use of the existing digital network will add a new wireless access system to the traditional wire access network. This diversification of access systems should make it possible to accommodate a broader spectrum of user needs in the future.

PHS devices promise to be a handy communicator that people can easily take with them wherever they go. Since the digital network will be able to manage the correlation between each terminal and its network address, it will usher in the stage of "terminal mobility." At some point in the future, however, it will become possible to manage the correlation between a terminal number and an individual's personal number, thereby achieving the stage of "personal mobility." As a result, it will be possible to provide every individual with true personal communications regardless of the type of terminal equipment involved (Figs. 7 and 8).

The ongoing progress of technology will likely lead to increasingly smaller and lighter devices with more sophisticated functions. The electronic organizers now on the market are already evolving toward the "personal digital assistant" (PDA) like Apple Computer's Newton, which incorporates communications capabilities. This convergence of various types of media and communications, including wireless E-mail, facsimiles and the like, will continue to advance in the coming years. The destination of this trend is the personalization of information, which will make it possible for individual and business users to take with them for use whenever and wherever they like the various types of multimedia information (including communications) that are available in their immediate surroundings.

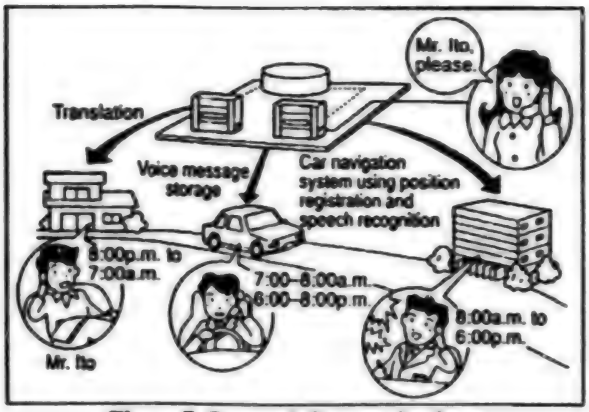

Figure 7. Personal Communications

Figure 8. Multimedia Age

To achieve this personalization of information and communications, it will be necessary to make full use of digital network capabilities and diversified access systems.

As the name Personal Handy-phone System implies, this move toward personal communications will start initially with the telephone. But an age is already unfolding before our eyes in which dramatic strides will be made toward ultrasmall designs, intelligent functions and multimedia capabilities. PHS service is only the first step toward this coming age, but it is a very important first step toward the realization of large dreams in the future. We believe it is the mission of NTT to make sure that those dreams come true.

An ISDN Basic Interface Videophone

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[Article by Hiroyuki Matsui, senior research engineer and supervisor, Human Interface Laboratories, NTT; Yasuhiro Tomita, engineer, Customer Equipment Division, NTT; Tsutomu Irishima, engineer, Visual Communications Sector, NTT, and Hisashi Ibaraki, senior research engineer, Human Interface Laboratories, NTT]

[FBIS Transcribed Text] *To promote visual communication services, we have developed a compact all-inclusive videophone that offers economical multipoint audiovisual communication for up to five terminals via the two B channels in the ISDN basic rate interface for each terminal, as well as providing point-to-point audiovisual communication. The videophone integrates a 5.6-inch color LCD, a 113-inch color CCD camera, and audio and video codecs in one compact desktop unit.*

This paper describes the configuration of the videophone, the multipoint communication method, and the video codec.

Introduction

Since ISDN basic interface service (INS-Net 64) was initiated in April 1988, NTT has been continually enriching its service menu and expanding its service areas. In June 1989, primary rate interface service (INS-Net 1500) was introduced, and packet switching mode service was started in 1990. To continue expansion of ISDN, various communication services that take full advantage of its characteristics, such as high-speed and high-quality transmission, have been proposed,[1-4] mainly to business users.

Now, the importance of moving picture communication is increasing in multimedia communication. In 1990, ITU-T and TTC standardized the codec for audiovisual services at p x 64 kbit/s, the frame structure for ISDN channels from 64 to 1,920 kbit/s, and the procedure for establishing communication between audiovisual terminals.[5,6] Various video codecs, videophones, and video conference systems have been developed based on these standards.[7-9] These systems provide face-to-face communication between, for example, personnel at a head office and those at branch offices.

Although audiovisual communication services conforming to the ITU-T standards and the TTC standards are considered to be among the most important applications for promotion of ISDN services, they are utilized only by business users at present. Thus, to expand the audiovisual communication market, it is necessary, not only to reduce terminal size and cost, but to also offer attractive functions to a wide variety of users. The terminals should also realize various applications with easy operation.[10]

It is for that reason that we have developed a compact all-inclusive videophone that provides multipoint audiovisual communication economically for up to five terminals via the two B channels in INS-Net 64 in each terminal, as well as providing point-to-point audiovisual communication. This videophone simplifies construction of a multipoint audiovisual communication system without center equipment (e.g., MCU: multipoint control unit) normally required in multipoint communication systems.

This paper describes the configuration of the videophone, the multipoint communication method, and the video codec.

1. Development Objectives

In order to enlarge the market for audiovisual communication services, they must be applicable to various other business usages, not just face-to-face video conferences. Thus, development efforts focused on the following objectives.

(1) Enriching the basic communication function as a videophone

(a) We adopted the standard telephone like human-machine interface to overcome user hesitation to operate a videophone.

(b) The visual privacy of the called party is ensured.

(c) External input and output of video and audio signals are supported so the videophone can be put to various uses by connecting various kinds of equipment to it.

(2) Realization of functions that will enable expansion of the audiovisual communication service market

(a) We realized economical multipoint communication that is constructed without center equipment, in order to offer such audiovisual services as multipoint teleconferences, multipoint monitoring, and multipoint lectures.

(b) We realized the high-resolution still picture communication functions often required in conferences, lectures, consulting, etc.

(3) We reduced the circuit size remarkably using VLSIs for the video codec, so that we could combine the video and audio codecs, a camera, and a display in one compact unit. Video processing for high-resolution still pictures was also realized using this video codec.

(4) We improved the control procedure to reduce connection time and ensure reliable interconnection with other vendors' videophones with recovery from irregular states.

2. Structure of the Videophone

2.1 Built-in Functions

Table 1 lists the main functions of the ISDN basic interface videophone.

Table 1. Main Functions of the ISDN Basic Interface Videophone

Item			Explanation
Basic functions	Calling operations	Directory dialing one-touch dialing	Previously registered calling numbers and communication mode (audiovisual or audio only) can be available by easy operation
	Cal' acceptance	Indication of communication mode	The communication mode can be recognized in the ringing state
		Automatic interruption of picture sending	Picture sending can be automatically interrupted. It can be made available again.
		Automatic response to an incoming call in the visual mode	A call in the visual communication mode can be automatically responded to. This function can be available for remote monitoring.
	Communication	Connection to external equipment	This videophone has external input and output connectors for audio and video signals, and can be connected to various external equipment
		Hands-free communication	Communication can be performed without holding the handset
		Sending interruption	Picture sending or voice can be interrupted. It can be made available again.
	Display	Picture-in-a-picture (P-in-P)	Sending and received pictures can be displayed at the same time. Sending picture can be displayed like a reflecting mirror.
		Superimpose	The number of the other party and the elapsed communication time can be displayed on the LCD
Multipoint audiovisual communication functions			This videophone offers multipoint audiovisual communication for up to 5 terminals using ring-type connection. The first calling terminal can control the transmission and reception of audio and video signals at the other connected terminals.
High-resolution still-picture communication functions			This videophone can send and receive high-resolution still pictures instead of moving pictures. High-resolution still pictures and moving pictures can be displayed at the same time.

For calling, there are convenient directory and one-touch dialing functions that can register both the calling number and the communication mode (audiovisual or audio only). Furthermore, these communication modes can be manually changed using extra communication mode (audiovisual or audio only) buttons.

For call acceptance, there are indication of communication mode and automatic interruption of picture sending to ensure the visual privacy of the called party. The communication mode is clearly indicated for call acceptance by the ringing tone and sound, the liquid crystal display (LCD) and an LED. When the called party accepts the incoming call, picture sending can be automatically interrupted. Furthermore, in order to be available for remote monitoring, this videophone has the ability to automatically respond to an incoming call in the visual mode.

For communication, the videophone has external input and output connectors for audio and video signals so that it can be put to various uses by connecting various kinds of equipment to it. Furthermore, hands-free communication is also provided so that the phone can accommodate more than one speaker.

For display, there is a picture-in-a-picture (P-in-P) display function, to confirm the picture that is being transmitted to the other party. In the calling state or the call acceptance state, the videophone automatically displays pictures being transmitted on a sub-area of the LCD in the audiovisual communication mode.

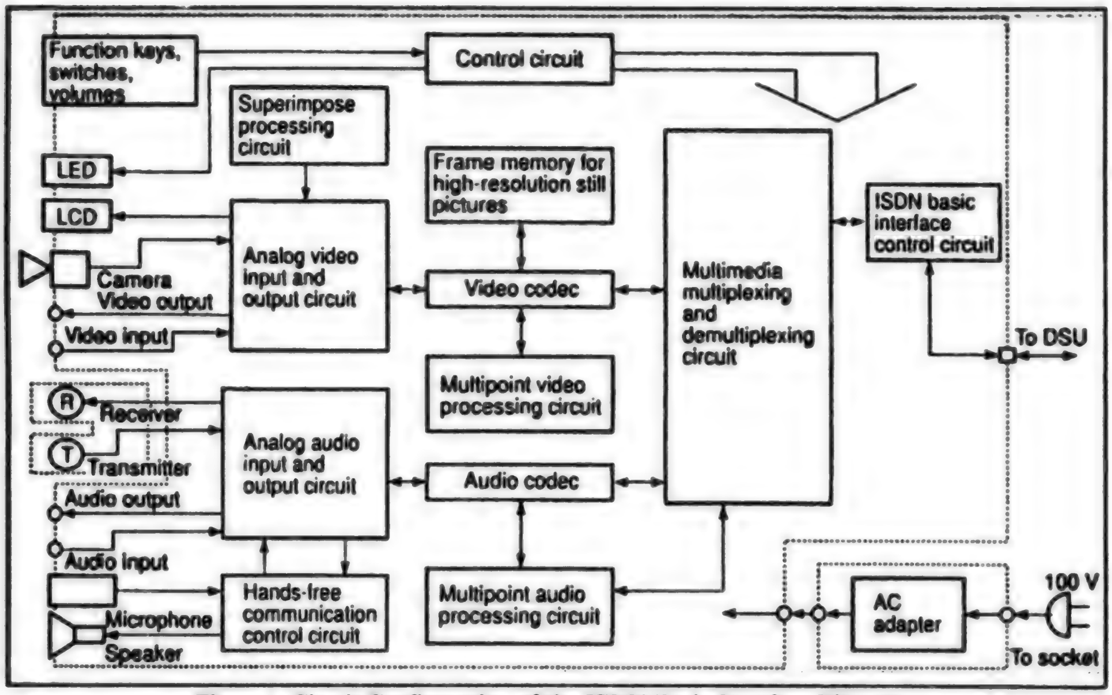


Figure 1. Circuit Configuration of the ISDN Basic Interface Videophone

Multipoint audiovisual communication can be established for up to five terminals using ring-type connection. The display on the LCD is divided into four received picture areas. The first calling terminal has priority in multipoint audiovisual communication, and that terminal can control the transmission and reception of audio and video signals for the other connected terminals.

High-resolution still-picture communication is effective for product introduction or consulting purposes. This videophone can display a received moving picture and a high resolution still picture at the same time using the picture-in-a-picture display function.

2.2 Circuit Configuration

The circuit configuration for the videophone is shown in Fig. 1, with the main specifications listed in Table 2. A new video codec was developed for this videophone. (The codec is described in Section 4.) The viewing angle of the fixed camera is set so that the picture area covers the upper half of the user's body when the videophone is on a desk and used for handset communication. Multipoint video processing and the high resolution still-picture processing are performed by a common video codec in order to reduce the external circuit scale. Multipoint audio processing, such as mixing the multipoint audio signals and audio coding processing, are performed by a common audio codec, as much as possible, for the same reason. The multimedia multiplexing and demultiplexing circuit multiplexes video and audio signals into transmission channels, and demultiplexes these signals according to the frame structure of, either one 64 kbit/s channel or two 64 kbit/s channels, in conformance with ITU-T H.221. Because the multiple connection capability is restricted to 2B, processing tasks were reduced and the circuit was realized as a one-chip LSI. The control circuit performs human-interface control, as well as audio and visual communication control.

Table 2. Main Specifications of the ISDN Basic Interface Videophone

Item	Contents
Configuration	A main unit and an AC adapter
Network interface	ISDN basic interface (INS-Net 64)
Functions	(See Table 1)
Camera	1/3-inch CCD camera with 250,000 pixels, full color
Monitor	5.6-inch back-light TFT LCD
Video codec	(1) Moving picture: CIF*1: 352(H) x 288 (V), conforms to ITU-T H.261 QCIF*2: 176(H) x 144(V), conforms to ITU-T H.261 (2) High-resolution still picture: 704(H) x 480(V), proprietary
Audio codec	(1) μ-112 (56 kbit/s), conforms to JT-G711 (2) A-112 (56 kbit/s), conforms to ITU-T G.711 (3) AD-PCM (24 kbit/s), proprietary
External connectors	(1) Video input and output connectors: Analog NTSC signal, $1V_{p-p}$, 75 ohm, unbalanced, EIAJ RC6703 connector (2) Audio input and output connectors: -14.7 dBm, unbalanced, EIAJ RC6703 connector

Table 2. Main Specifications of the ISDN Basic Interface Videophone (Continued)

Item	Contents
Audiovisual communication modes	(1) Video signal rate: 100.8 kbit-s Audio signal rate: 24 kbit/s (2) Video signal rate: 68.8 kbit/s Audio signal rate: 56kbit/s (3) Video signal rate: 38.4 kbit/s Audio signal rate: 24 kbit/s, etc.
Multipoint communication	(1) Maximum number of terminals: 5 (2) Multipoint connection method: Ring type (3) Display mode: 4 areas/1 area/PinP
Dimensions	(1) Main unit: 240(W) x 230(D) x 227(H) mm (2) AC adapter: 92(W) x 165(D) x 35(H) mm
Weight	(1) Main unit: Approximately 2.5 kg (2) AC adapter: Approximately 0.5 kg
Note 1: Common intermediate format	
Note 2: Quarter common intermediate format	

2.3 Display Device and Operation Keyboard Structure

To decrease device scale and to reduce cost, a 5.6 inch full-color LCD is used for displaying pictures. Operation instructions are also displayed on the LCD as a matrix of 12 lines by 24 characters per line for easier viewing. The camera is fixed just above the LCD to maximize the correspondence between the viewing axis of the camera and the gaze direction. To permit this videophone to be used in various settings, the viewing angle of the camera and LCD can be adjusted. To encourage operators dealing with this videophone for the first time, it has made as easy to use as the standard telephone. The operation keyboard structure and the human-machine interfaces of this videophone follow those of conventional telephones as much as possible. The one-touch dialing buttons just below the LCD correspond to the operation items displayed on the LCD.

2.4 Exterior Appearance, Design

In considering design, attention was focused on the following points.

- The pursuit of an excellent design that would promote the popularization of ISDN NTT's videophone, differs from previous videophone designs and, at the same time, suggests a high-class item with a high level of added value.
- Emphasis on ease of use and comfort in operation as an excellent tool.
- Harmony in various environments where this videophone is used.

An exterior view of the videophone is shown in Fig. 2 [not reproduced]. By following the image of the standard telephone and adopting a familiar, roundish design, we aimed at the pursuit of reliance, peace of mind and kindness, and of overcoming the user's hesitation to operate a videophone.

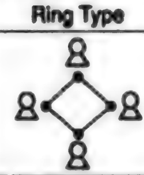
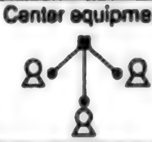
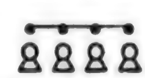
In consideration of its being set on a desk, the videophone was made as small as possible. On the other hand, we pursued easy operation by providing a large operating panel. The color of the videophone is gray, with a high-grade matte finish, to conform to the business environment.

3. Multipoint Audiovisual Communication System

3.1 System Structure

In response to demands for multipoint video conferencing and multipoint monitoring, this videophone has a proprietary multipoint communication function, as well as the standard point-to-point communication function of usual videophones.

Table 3. Comparison of the Multipoint Connection Methods

	Ring Type	Star Type	Chain Type
Connection Topology		Center equipment 	
Center Equipment	Unnecessary	necessary	Unnecessary
Transmission Rate*	Up to 128 kbit/s	Up to 128 kbit/s	Up to 64 kbit/s
Connection Terminal Capacity	Several	Many	Not so many
Multipoint Control Method	Distributed	Concentrated	Distributed
Other Features	No need to have a large number of channels at each terminal. Economical by connecting according to the most suitable route	Need to have a large number of channels at the center equipment Heavy load at the center equipment	No need to have a large number of channels at each terminal. Economical by connecting according to the most suitable route
*When using one ISDN basic interface per terminal			

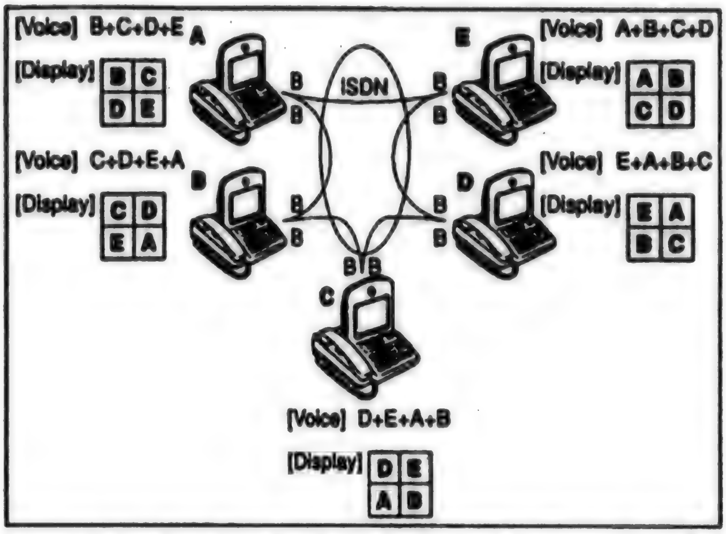


Figure 3. The Ring-Type Multipoint Audiovisual Communication System

There are several methods of establishing a multipoint connection using the B channels of the ISDN basic interface. The most common topologies are the star-type connection, the chain-type connection[11-13], and the ring-type connection. A comparison of these topologies is shown in Table 3. Using the ring-type connection, 128 kbit/s data can be transmitted through one B channel forming two loops to simultaneously transmit 64 kbit/s data in both direction. The ring-type connection also allows easier system construction and no center equipment is needed.

As shown in Fig. 3, the multipoint audiovisual communication system is constructed using two B channels for up to five videophones.

3.2 Multipoint Connection Control

To establish the multipoint connection shown in Fig. 3, terminal A calls terminal B, terminal B calls terminal C and so on until terminal E calls terminal A. This procedure is shown in Fig. 4.

To simplify the establishment of this type of multipoint connection, the user of terminal A registers in advance all addresses of the terminals with which the user intends to communicate. When establishing the multipoint connection, the user simply chooses the group required. Terminal A sends a connect indication command, including the next terminal's address to terminals B, C, D, and E automatically, so that users at these terminals do not need to be actively involved with connection establishment.

If a line is busy when called, the terminal is automatically skipped, and the next terminal is called. This method makes the establishment of the multipoint connection more reliable.

3.3 Video and Audio Processing

For a simple and useful human-machine interface in multipoint conferences, the four pictures received from the four other terminals are displayed on the LCD, which is divided into four areas, as shown in Fig. 3. This divided display is realized by constructing one CIF (Common Intermediate Format) picture from the four QCIF (Quarter-CIF) pictures from the remote terminals. As shown in Fig. 5, each terminal extracts the next terminal's picture from the received CIF picture, rearranges the four QCIF pictures' locations, inserts its own picture, and then transmits the resulting CIF picture to the next terminal. When the user wants to view his own picture, it is displayed using the picture-in-a-picture function.

As for audio processing, each terminal adds its own audio signal to the incoming audio signal and retransmits to the next terminal. This permits all terminals to talk to each other at any time.

4. Architecture of the Video Codec and Connection Enhancement

4.1 Video Codec

The configuration of the video codec is shown in Fig. 6. This very small video codec is constructed around two new LSIs: a video interface LSI (VIF LSI) and a codec LSI (CODEC LSI).

The VIF LSI consists of a Y/C separator, a Y/C compositor, a CIF transformer and an NTSC transformer. An inputted digital NTSC signal is separated into Y and C signals by the Y/C separator, the CIF transformer transforms these signals into signals based on CIF as described in ITU-T H.261, or on QCIF which has half the number of pels and half the number of lines of CIF. The NTSC transformer transforms the received signals based on CIF or QCIF into Y and C signals. The transformed Y and C signals are converted into NTSC signals by the Y/C compositor. This LSI has a noise reduction circuit to remove noise from the video signal and improves the quality of the coded pictures. It also includes a high-resolution still-picture processing circuit and picture-in-a-picture processing circuit that can superimpose a small video window on the main video, and can select the sending

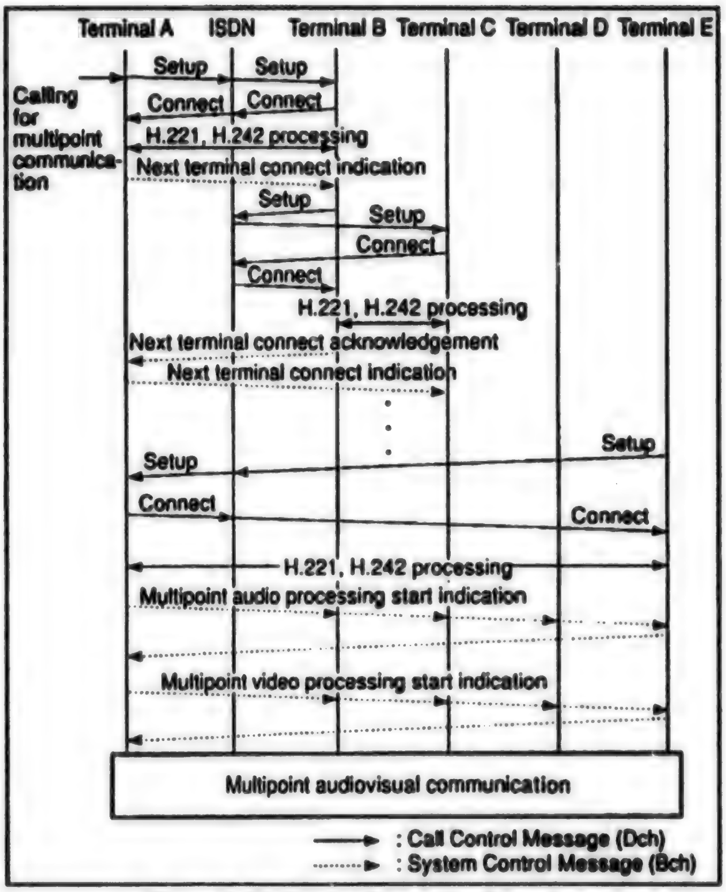


Figure 4. Multipoint Connection Procedure

picture, received picture or high-resolution still picture. The video signals processed by the VIF LSI are stored in the frame memories and are fed into the CODEC LSI.

The CODEC LSI consists of a motion compensation circuit, a discrete cosine transform (DCT) circuit, an encoding circuit, and a decoding circuit. The motion compensation circuit reduces temporal redundancy, while the DCT circuit reduces spatial redundancy in the video signal. The encoding circuit compresses the reduced video signal and the decoding circuit decompresses the compressed video signal. To reduce the scale of the coding circuit, the high-resolution still-picture coding function, which is essential for high resolution services, is performed by the ITU-T H.261 video codec. Many discrete circuits are supplanted by these LSIs.

The size of the video codec and its power consumption are less than half those of conventional video codecs.[14]

4.2 Control for Interconnection

This videophone supports interconnection control functions to reduce connecting time and increase interconnection reliability. In general, videophones have various audiovisual communication modes and it is necessary to exchange information on decoding capabilities to achieve interconnection. For instance, any mode difference increases the time required to harmonize the capabilities from 0.1 to 0.8 seconds. The videophone sends only the capabilities appropriate for the selected mode of audiovisual communication to reduce connecting time. On the other hand, to realize reliable interconnection, a procedure is added that recovers from any irregular state caused by transmission errors or for other reasons. Accordingly, this videophone monitors the status of received signals. If the status becomes irregular due to synchronization error, the decoder resets itself and requests an intra-coded frame to ensure recovery from the error.

Conclusion

A compact all-inclusive videophone featuring multipoint audiovisual communication functions and high-resolution still-image communication functions has been developed. One of its goals is to expand the ISDN visual communication service market.

(1) The videophone was developed for INS-Net 64 and offers the important communication functions as a video phone, e.g., an automatic interruption of picture sending function to ensure the visual privacy of the called party.

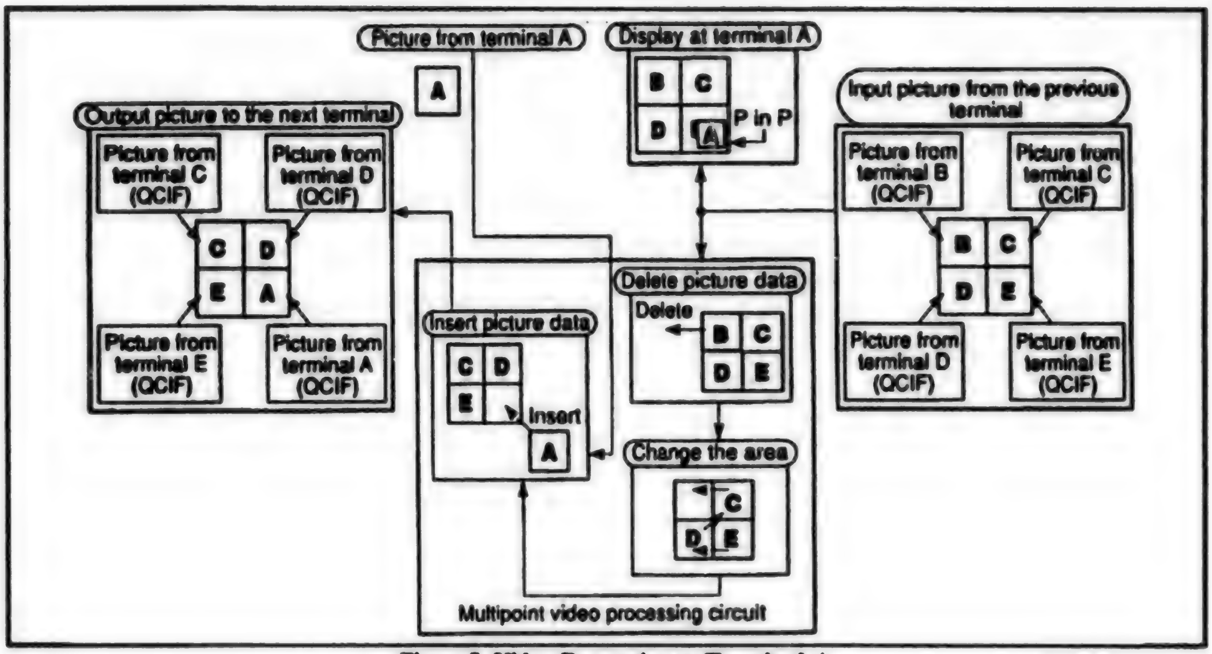


Figure 5. Video Processing at Terminal A

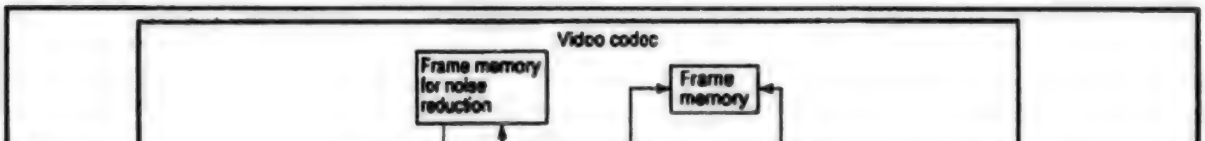


Figure 6. Video Codec Configuration

(2) The videophone can provide multipoint communication for up to five terminals using ring-type connection. This connection method is very economical because no center equipment is needed.

(3) The circuit scale of the videophone has been remarkably reduced by development of two new VLSIs for the video codec. These VLSIs also offer high-resolution still-picture transmission functions.

(4) We have introduced an interconnection control method that reduces connecting time and increases interconnection reliability.

This videophone has been on the market in Japan since December 1993. We will continue to study new audiovisual communication services to further expand the ISDN communication service market in the future.

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Nippondenso Co., Ltd. Develops Revolutionary New Micromachining Technology

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[Article by Tadashi Hattori, Doctor of Engineering, Assistant Director, Nippondenso Basic Research Institute]

[FBIS Translated Text]

Micromachining To Revolutionize Machinery

The apex of semiconductor technology is becoming visible, while new possibilities are being created in mechanical engineering, which had become stagnant. The Basic Research Institute of Nippondenso Co., Ltd., is involved in micromachining research, with the goal of revolutionizing existing machining processes through the use of physics-based knowledge about physical properties, which was nurtured by semiconductor technology.

Mechanical engineering has developed over the last 20 years because of new strides in the field of electronics. The influence of semiconductor devices has been particularly great.

However, the apex of that semiconductor technology, which has greatly affected the development of mechanical engineering, is becoming visible.

In the area of silicon technology, the line width of circuit patterns that make up LSIs (large-scale integrated circuits) already is at the half-micron level (around 0.5μm). Henceforth, further development can be anticipated if line width can be halved to the quarter-micron level (around 0.25μm), but its impact is predictable. The extent to which future advances in semiconductor technology will affect the application of semiconductor devices to automobile control, at least, can be surmised.

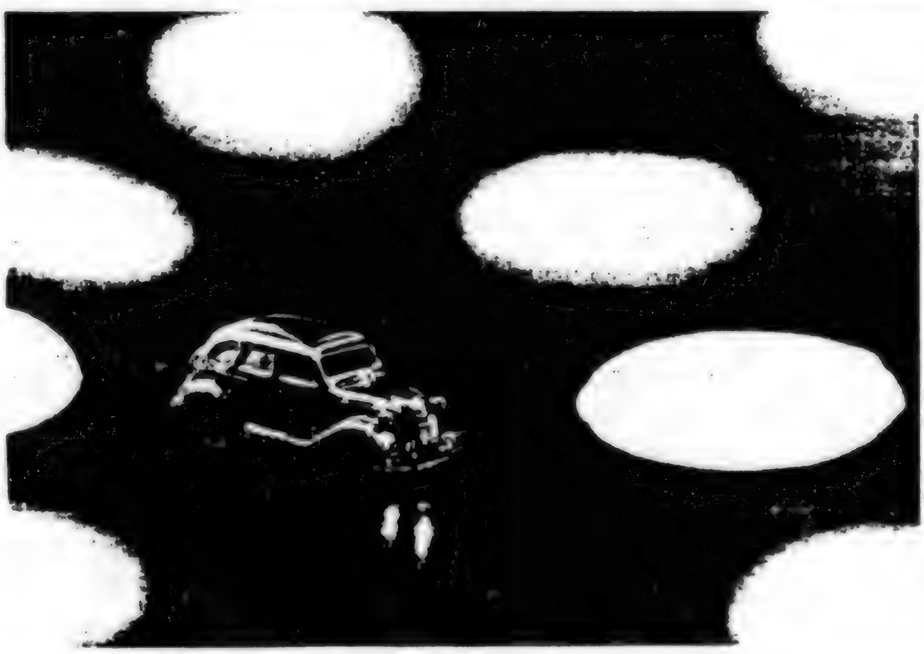
Silicon is not the only material used for semiconductors; there are compound semiconductors as well. Nippondenso has worked on compound semiconductors, with emphasis on high speed and high frequency. Although the range of communication frequency bands is rising higher and higher, it is possible to say that the 60 GHz band, or the 90 GHz band, will be the limit for now.

If we take another look at various technologies now that the apex of semiconductor technology is becoming visible, we realize that possibilities for future development exist in mechanical engineering.

Close Investigation of Machining From Viewpoint of Physics

Developments in mechanical engineering have been sustained by incorporating successful semiconductor technologies. However, we have neglected to make efforts to revolutionize mechanical engineering itself. In Nippondenso alone, there has been a considerable decrease in researchers in the fields of thermal engineering, fluid dynamics and machining when compared to 20 years ago. In mechanical engineering as an academic discipline as well, control theory, numerical analyses and other computer application sciences are the only areas in the spotlight. Research still continues on new processing techniques, but a limited number of researchers are involved.

Nevertheless, fields that have stagnated over some time also offer opportunities for revolutionary development. Semiconductor technology has provided the means to observe molecular, atomic and other micro-level phenomena. We can search for new approaches by applying



Microcar Smaller than Grain of Rice

these methods to mechanical engineering. Therein lies the possibility of a breakthrough.

For example, we have searched for lubrication technologies by using different varieties of oil for various sorts of surface treatment and then studying friction and abrasion through macroscopic observation. It is only natural, however, to expect that new knowledge can be acquired by conducting microscopic research—observing the action of individual molecules and atoms on the surface of substances—as is done with semiconductor technology.

If mechatronics was born from the incorporation of semiconductor technology, then mechanical engineering of the future is the application of methods used in semiconductor technology. Mechanical engineering actually includes a broad range of fields. The question is: Which fields should be focused upon in order to incorporate the methods of semiconductor technology and recompose mechanical engineering itself?

Eight years ago, Nippondenso formed an internal committee to deliberate the future of the company from the viewpoint of R&D. I was selected as a member of this committee, which included top executives of the company, in which lively debate was carried out. One conclusion made by this committee was that we should vigorously pursue the goal of miniaturization.

The company's Basic Research Institute, opened in 1991, was based on the deliberations of that committee. In the Institute, a 4,000 sq m (square meter) clean room for semiconductor research is adjacent to a 3,000 sq m laboratory containing conventional machining equipment. This equipment is used by experts in material, software, mechanical design and electronic design to conduct research on new processing methods.

Microcar Expresses Dream for the Future

We decided to use the term micromachining for the new processes we were researching. Since the direction of research had been set through full discussion and consensus, the Basic Research Institute began its activities without any special cares or concerns.

We considered what could be shown to the people that were invited to the opening ceremony of the Institute in order to create intuitive understanding of our research goals. Microphotographs of semiconductors would not be very interesting, even if they showed compound semiconductors or how many microns were in a line width, and a display of gears made by conventional machining would not be interesting either.

Ultimately, we displayed a 1/1000 model of a "Toyoda AA" classic car. The model was made with conventional machining technology and sacrificial layer etching, a semiconductor fabrication technique. It expressed our dream for the future, which was to create micromachines by the use of new processes and in them incorporate intelligence and the senses of sight and hearing.

The newspapers reported on the microcar, which was smaller than a grain of rice, and precisely recreated the Toyoda AA. At around that time, MITI was beginning to study themes for an industrial science and technology R&D system (abbreviated as industrial technology projects; called large-scale projects at the time). A newspaper article on the microcar caught the eye of members of the industrial technology projects survey committee. When shown the actual microcar, they expressed great interest, and added micromachining to the themes for industrial technology projects.

A number of microcars were made thereafter. In one case, color was added by means of thin film. Another microcar was made of a film 30μm thick, which was made by plating on a form that was made by machining and then removed. The microcar was even listed in the Guiness World Book of Records.

We did not have miniature robots in mind when we made the microcar. We were thinking of a machine to be produced by Nippondenso in the future, which would consist of a miniature framework containing sensory capabilities and intelligence. Our image coincides precisely with the machine that is the goal of the "micromachine" industrial technology project.

Reconsider Processing From Molecular, Atomic Viewpoint

Micromachines are not the only goal of our micromachining research. I think there are many fields that can be revolutionized by looking at processes at the molecular or atomic level, even if the machines themselves are not reduced much smaller than existing machines.

Surface roughness, for example, normally is expressed in figures derived from macroscopic measurement, such as center line average height or maximum height. However, processing methods are bound to change substantially if surface roughness is examined in terms of surface level, what kind of oxide film is on the surface, and what kinds of molecules or atoms are adsorbed and in what manner.

An excimer laser uses laser processing, instead of just the use of a carbon dioxide laser to provide heat for melting, for ablation. Electric discharge machining, instead of just cutting holes with electric discharge, can be enhanced by the addition of chemical reactions. Processes using lathes, milling machines and other conventional types of machining can also be modified by incorporating the thinking behind semiconductor technology.

Material hydrophilicity, lubrication and surface roughness can be taken a step further and studied from the atomic level. The analysis of flow, when it reveals the behavior of individual molecules, can provide understanding of flow inside vacuum equipment.

There are countless fields that can be topics of micromachining research. Our research is not limited to processes using relatively new methods such as ion implantation, ion beams, laser beams, electron beams or SOR (synchrotron orbital radiation). We believe that conventional machining can also be changed substantially by slight modifications from the viewpoint of physics.

Application to Sensors Imminent

The simplest application of micromachining is in the production of machines that do not do much work. A typical example is sensors. Nippondenso mass-produces

acceleration sensors used in airbags. Such sensors, which pick up signals through motion, are promising areas for the application of micromachining.

Machines that do not do work also include machines that deal with light. The Basic Research Institute is studying bidimensional scanning mechanisms as well as variable focus mirrors and lenses, which work by using fluid pressure or static electricity to change curvature.

We already have developed an LSI that measures, with 0.5 ns (nanosecond) resolution, the time for return of reflected light from a laser. We also have test-manufactured a system, which combines this LSI with a microscopic scanning device, that immediately detects an object's contours and distance from the object. A CCD (charge coupled device) camera operated from a workstation had been used to calculate the distance. Now that a time-measuring LSI and a small scanning device can do the work, the fields of application will increase greatly.

One example is a replacement for the barcode reader, which Nippondenso mass-produces. Application to automobiles also looks promising. There are trucks that currently are equipped with laser radars that measure distance between vehicles, but these laser radars can only measure the distance from the vehicle immediately in front of the truck. A scanning function is needed in order to cover a wide field of vision. At present, airbags are inflated when acceleration at time of impact is detected, but a safer vehicle can be made if laser scanning can be used to detect unusually rapid approach to another vehicle or object before actual collision.

In addition to sensors and optical devices, application to mechanisms that do a little more work include electrical and light switches.

Creation of New Machines

Sensors, optical devices and switches are areas where anyone can easily envision micromachining application. Beyond that, we are thinking of application to valves.

For example, high-precision machining is needed for certain parts of fuel injection valves for automobile engines, so it is done in a clean room. The fuel injection valve has been reduced in size, but its weight and measurements are greater than necessary for the actual functioning part, which goes on and off in an aperture of about 0.3 to 0.8mm. Hydraulic or pneumatic electromagnetic valves are similar to fuel injection valves. Micromachining would make it possible to make these types of valves much smaller and lighter. The secondary benefits of increased responsiveness and reliability could also be expected.

As a matter of course, the Basic Research Institute will conduct research on the application of micromachining to automobile parts and other production fields in which Nippondenso has been involved. It does not want to stop there, however. The company has a strong desire to create new mechanisms and machinery that will build up new markets.

One example of a new mechanism that would be created by micromachining is a miniature inspection robot, which is viewed as a promising mechanism by many researchers.

There is a strong demand for a miniature inspection robot. A maintenance robot for power generation facilities is listed as a research topic under the "micromachine" industrial technology project. There are many uses for a miniature robot that can inspect as it moves, even if it is several centimeters rather than several millimeters in size.

Getting Results Out as Soon as Possible

The DRAM (dynamic random access memory) chip is a representative example of microprocessing, but in DRAM research, everyone is competing for the same things: smaller linewidth and increased integration. Would it be an overstatement to say that the only competition is over who will be first? Micromachine research is somewhat different.

All sorts of materials can be used, not just silicon, but also ceramics, plastics, and metals. We are researching micromachining from the viewpoint of the automobile industry, but there are other researchers looking at it from the medical field and the heavy electric machinery industry. I do not think that anyone has a clear picture of how micromachine research as a whole will be systemized. It is hoped that systemization of research will be one of the significant accomplishments of MITI's industrial technology projects. To accomplish this, systemization of micromachines should be seen as important, according to Hiroshi Kasai, R&D officer of the Agency of Industrial Science and Technology. Semiconductor technology experts are leading the research on micromachines in the United States and Europe, whereas mechanical engineers have taken the lead in research in Japan. I believe that Japan is in a more favorable position as far as building a micromachine technology system is concerned.

We anticipate systemization from the industrial technology projects, but at the same time, we will also do our own work on systemization of micromachining. In that endeavor, we will respect existing machining, but we will also use physics-based knowledge gleaned from research on the physical properties of semiconductors, and we want to present our results to the world as soon as possible. That is our dream.

The words of Takayuki Hirano, managing director of the Micromachine Center, Inc., are the best way to end this article. Truly, this is "a renaissance in mechanical engineering."

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